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TOXICITY OF MALEIC HYDRAZIDE IN CALIFORNIA SOILS[1]

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INTRODUCTION

THE STUDIES presented in this paper are an attempt to answer certain questions involved in the relations between maleic hydrazide (1,2 dihydropyridazine—3,6 dione) and different soils. These questions grew out of the fact that maleic hydrazide may acquire importance as a selective herbicide if proved successful in field tests and that spray residues left on the soil may affect subsequent crops. The studies may also indicate the value of maleic hydrazide as a temporary selective soil sterilant or as a preëmergence spray.

Maleic hydrazide when pure is a white crystalline solid, soluble 0.4 per cent in water at room temperature, and slightly acid in reaction. It has been prepared in various formulations, among which is the water-soluble diethanolamine salt (Schoene and Hoffman, 1949).[4]

Research already conducted on this chemical furnished some data on its effect on plant growth. Experiments by Schoene and Hoffman (1949) indicated that maleic hydrazide had temporary but strong inhibiting effects on plant growth.

Currier and Crafts (1950) in screening experiments, showed that 0.2 per cent spray killed two-weeks-old barley, yet had no apparent effect on five-weeks-old cotton. They reported that the age of the plant was critical; for example, cotton in the cotyledon stage was severely inhibited and older grasses were less susceptible than young grasses. In general, grasses were found to be more susceptible to maleic hydrazide than broad-leaved plants; and broad-leaved plants were found to be more tolerant the more mature they were at spraying time (Crafts, Currier, and Day, 1950).

Subsequent investigations by Crafts, Currier, and Day (1950) indicated that maleic hydrazide was a growth regulator of the hormone type and could be translocated by plants.

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Naylor and Davis (1949), observing a large accumulation of sugar in the leaves and stems, as well as development of anthocyanin pigments, suggest that possibly maleic hydrazide exerts its effects on plant metabolism, primarily through a disruption in the sugar breakdown and utilization. The appearance of sugar exudates on the leaves of sprayed plants was observed independently on barley (var. Sacramento) at the University of California, Davis, and development of anthocyanin pigmentation was also reported by Currier and Crafts (1950). Currier, Day, and Crafts (1951) have reported an accumulation of fructosan in barley leaves and have shown that the exudate from barley leaves is largely sucrose. Crafts, Currier, and Day (1950) showed that applications of maleic hydrazide are additive and that breakdown of the chemical, once it has been absorbed by the plant, is slow.

The work presented in this study aimed at determining:

1. The initial toxicity of maleic hydrazide in various California soils and the change in toxicity as the soils were repeatedly cropped
2. The effects of percolation on the distribution of the compound in columns of air dry soil
3. The possibility of leaching the chemical at depths where it would not cause damage to crops subsequently grown.

MATERIALS AND METHODS

Diethanolamine salt was used in all the tests interpreted in this study. The chemical was prepared by the Naugatuck Chemical Division of the United States Rubber Company at Naugatuck, Connecticut. Kanota oats was used as a plant indicator in all the tests. One experiment used one soil type (Yolo clay loam), the same range of concentration of maleic hydrazide, and different plant indicators. The results of this test are shown in table 6.

The principal characteristics of the soils used can be summarized according to Storie and Weir (1948) and to Cole (1949) as follows:

Soil series	*General reaction*	*Parent material*	*Order*	*Class*	*Great soil group*
Aiken	Slightly acid	Basic igneous	Zonal	Pedalfer	"Podzolic" (from lateritic material)
Arbuckle	Neutral	Sedimentary	Azonal	Pedalfer	Alluvial
Egbert	Slightly acid	Mixed organic	Intrazonal	Pedalfer	Bog
Hanford	Neutral	Acid igneous	Azonal	Noncalcareous pedocal	Alluvial
Rocklin	Slightly acid	Acid igneous	Intrazonal	Noncalcareous brown	Planosol
Sierra	Moderately acid	Acid igneous	Zonal	Pedalfer	Podzolic
Stockton	Basic	Basic igneous	Intrazonal	Pedocal	Wiesenboden
Yolo	Neutral	Sedimentary	Azonal	Noncalcareous pedocal	Alluvial

All of these soils were air dry samples, pulverized and screened before use. These studies were carried out in the greenhouse under partially controlled conditions.

TOXICITY TESTS

The tests were conducted by the methods first described by Crafts (1935). The advantages of such methods led to their use by Crafts in a number of subsequent works and by Schwendiman (1941) in studying the relations between soils and various herbicides.

Preliminary series were set up. These consisted of four replicates, in which Yolo fine sandy loam and concentrations of 0.0, 1.0, 10.0, 100.0, 1,000.0, 5,000.0, and 10,000.0 p.p.m. maleic hydrazide (air dry soil basis) were used. The results of repeated croppings are shown in table 1.

Subsequently, three replicated series were grown on 11 soils. In these series different concentrations in a smaller range were used: 0.0, 5.0, 15.0, 40.0, 80.0, 140.0, 220.0, 340.0, 490.0, and 680.0 p.p.m. maleic hydrazide in the air dry soil.

The chemical was measured from a stock solution, diluted to a total volume sufficient to bring the soil in the can to its field capacity, and added in three increments. The cans were not perforated; therefore no loss of chemical occurred during watering, which was done by weight.

Thirty days after planting, the crop was cut off at ground level, its height measured, and its fresh weight recorded. When the first crop was harvested, the tops of the plants were returned to each can. After 30 days, the dried soil was pulverized, the tops placed in the empty cans, and the soil poured in. The cultures were then watered to field capacity and seeded to determine changes in toxicity. The procedure was repeated, and three croppings were made in each instance.

The results of this test are shown in figures 1 to 11 and in table 12. As table 2 indicates, no correlation could be found between toxicity and clay content.

Comparison of fresh weights of original crop yields of controls for the different soils in table 3 shows no consistent relation between fertility level and toxicity or subsequent inactivation of maleic hydrazide.

To reach these conclusions, Kanota oats, germinated and grown in quartz sand to a height of about 5 cm were transplanted and grown in water-culture solutions. In painted quart Mason jars three fertility levels were set up, equivalent to 0.5, 1.0, and 2.0 complete Hoagland solution (Hoagland and Arnon, 1950). The following amounts of maleic hydrazide were added: 0.0, 5.0, 15.0, 40.0, 80.0, 140.0, 220.0, 340.0, 490.0, and 680.0 p.p.m., culture solution basis.

The reaction of the solutions was checked at regular intervals with universal indicator paper and found to be slightly acid (pH about 6.0). Five oat plants were transplanted in each instance; no provision was made for aeration. Separate jars provided with aeration did not show any difference in toxicity. After 15 days, all plants at concentrations above 40.0 p.p.m. were dead and dried. Mildew, which appeared about 20 days after start of the cultures, was particularly abundant on the 5.0 p.p.m. cultures compared with the controls. No dusting application was made.

After 30 days total fresh weights were recorded; no difference in toxicity was found among the three fertility levels.

Table 4 shows that the reaction of the soil did not seem to affect either the initial toxicity or the inactivation of maleic hydrazide. Similarly, as shown by

table 5, no relation could be found between the per cent water in the soils at field capacity and the chemical toxicity.

The effect of nitrate concentration was investigated by leaching columns of Yolo clay loam with water, and comparing the toxicity of maleic hydrazide in this soil, now presumably low in nitrates, with normal Yolo clay loam. No difference was found in the first cropping, and no significant divergences occurred subsequently.

Results indicated an increase in fertility in such soils as Aiken clay loam, Yolo adobe clay, and Stockton adobe clay during the first cropping, at very low concentrations of maleic hydrazide. Increase in yield from treated soils, compared with yield from untreated soils is very apparent in all soils during the second and third croppings. One exception is Arbuckle clay loam, which showed an increase in yield only at the third cropping. Even though we have to account for mineral nutrients not utilized yet still available in the soils in which little or no growth occurred in the previous crop, there is a clear indication that the inactivation of maleic hydrazide is accompanied by an increase in fertility. This may be due to nitrogenous compounds made available through the hydrolysis or microörganic decomposition of the chemical. The salt used was a diethanolamine, and the acid itself contains two -NH groups.

It has been suggested that the iron from the tin cans might be a factor in the decomposition of maleic hydrazide in these tests since it is known that iron salts of the compounds have not been successfully synthesized because of instability. This factor probably caused no error in the experiments considered here, as the degree of rust varied according to the condition of the cans used and some cans were new and unrusted. Triplicates were used, and had the factor of rust actually caused error, this would have appeared in the course of the experiment, but actually did not.

It is perhaps worth noting that yields smaller than 0.1 gm were considered negligible. Such cultures were considered sterile; oat plants did germinate, but showed no subsequent growth. When growth inhibition occurred, only the first leaf of the oat plant showed anthocyanin pigmentation at harvest time.

Egbert loam behaved erratically, yet when leached with large quantities of water behaved normally. Results are reported in figure 9 and table 12. This same soil did not behave anomalously in other experiments carried out in the greenhouse, and no explanation is offered, except perhaps that a high salt concentration may have accumulated in the particular sample used here.

From the previous discussion and a consideration of the soils and conditions under which they were studied, it may be stated that maleic hydrazide in soils varies in toxicity. Sterility was obtained from 15.0 to 140.0 p.p.m., air dry soil basis, and the inactivation after two months under greenhouse conditions varied from slight to complete in the range of concentrations considered. These initial and residual toxicities seemed inherent to each soil and not due to any common characteristic.

The initial toxicity of maleic hydrazide in Yolo clay loam to various plant indicators is shown in table 6, and plate 1.

As can be seen, at 5.0 p.p.m. maleic hydrazide there was an increase in weight in four instances—flax, sunflower, watergrass, and watermelon—com-

pared with check yields. This increase, however, is probably significant only for watergrass and watermelons.

DISTRIBUTION OF MALEIC HYDRAZIDE IN SOIL COLUMNS

The procedure followed in this test (Crafts, 1935) included the use of celluloid soil tubes filled with air dry soil and moistened from above by a constant flow of stock solution. No water accumulated on the top, and none ran down the sides of the column. Chemical sufficient to sterilize the whole column was diluted in enough water to wet all the soil. There was practically no loss of soil solution. After complete moistening, the tubes were left for 24 hours to reach equilibrium before being opened and cut into 10 equal portions. Each portion was mixed, with care taken to reduce puddling of the wet soil. Each portion was placed in a no. 2 can and seeded with Kanota oats. Controls of the different soils were set up simultaneously. After 30 days the tops were cut off; and the procedure that was used in recropping the toxicity series was also used in this test.

The six soils tested were Sierra fine sandy loam, Yolo fine sandy loam, Hanford loam, Aiken clay loam, Yolo clay loam, and Stockton adobe clay. Except for the Aiken clay loam, the behavior of these soils was quite similar.

Tables 15 and 16 show the results of these tests. As was expected from the conclusions reached in the toxicity determination, no maleic hydrazide fixation occurred on the clay particles. The chemical moved with the soil solution, was available to plants, and inhibited all growth in the whole column.

In the Aiken clay loam, however, only the top 30 cm showed no growth, which indicated an accumulation of available maleic hydrazide in this region. The behavior of this soil indicates that in the soil solution maleic hydrazide behaves as an anion. This would also confirm its repulsion by clay particles. Murphy (1939) showed the very large phosphate fixation of Aiken clay loam. He was able to fix 2,372 mg of phosphate per 100 gm of soil. He also showed an increase in the base exchange capacity with increase in phosphate fixation in kaolinite. Aiken soils are supposed to have a kaolinitic clay structure. It was thought, therefore, that by saturating a column of Aiken clay loam with phosphate no fixation of maleic hydrazide would occur, unless it could displace the phosphate from the kaolinitic structure. Phosphate was added at a rate of 2,840 mg per 100 gm of soil as KH_2PO_4. Excess phosphate was leached with 1,000 cc of water, then maleic hydrazide was added. No fixation was observed. The chemical moved with the soil solution, and no growth was obtained in any increment of the column (tables 13 and 14 and plate 2).

The fact that maleic hydrazide could not displace phosphate adsorbed on the Aiken soils was thought to be an important factor in the inactivation of the chemical by displacement through these kaolinitic soils. The procedure was then reversed, that is, maleic hydrazide was added, then 2,840 mg of phosphate per 100 gm of soil. The herbicide was displaced to a certain extent; moving ahead of the phosphate, it was able to fix itself on the soil, inhibiting all growth in the top 60 cm of the column. The phosphate, however, did not displace the maleic hydrazide completely, and growth was normal in the lower 40 cm of the column.

It is worth noting that after treatment the Aiken soil lost its characteristic granulation and acquired a small crumblike structure. Also, evaporation was much faster in treated than in untreated soils. These points were not investigated and no explanation is offered.

As will be shown later, subsequent investigations proved that water alone could displace maleic hydrazide from soils, including Aiken clay loam. The same quantity of water (1,500 cc) displaced the maleic hydrazide toxicity region from 0–30 to 30–60 cm depth, growth being normal in the top 30 cm fraction. The fact that no maleic hydrazide was leached out is confirmed by the cultures grown in the collected soil leachates mentioned later, which showed no sign of inhibition or toxicity. The unexpected difference between the behavior of maleic hydrazide in Aiken clay loam when leached with water or with KH_2PO_4 remains unexplained. Large amounts of water seem to inactivate maleic hydrazide, with a simultaneous increase in fertility of the soil, which can be ascribed to a possible hydrolysis of the chemical. Columns of Aiken clay loam leached with 1,500 cc of water yielded 3.9, 3.0, and 2.6 gm of plants respectively for the first, second, and third increments of soil, as compared with 2.4 gm for the control. When the same volume of KH_2PO_4 solution was added, no growth occurred in any of these increments (control gave 2.6 gm).

In Aiken clay loam a close relation exists between maleic hydrazide displacement, inactivation, and KH_2PO_4 solution or any of its ions. The nature of this relation remains to be determined.

The very large quantity of KH_2PO_4 used (1,500 cc of 1.5 M. solution) might suggest that the osmotic pressure of the soil solution, the potassium toxicity, or the pH change caused by anion exchange in kaolinite are influencing factors in the sterility shown by this treated soil. While these factors actually may be entering into the picture, they should not be given more importance than they deserve, because the bottom 40 cm of soil (60 to 100 cm depth), which were submitted to the same treatment, showed growth very similar to the untreated control. However, no actual osmotic pressure, pH, or available K determinations were made during this experiment.

The fact that Aiken clay loam is a soil with a high Fe content was also considered. Another soil, the Sierra fine sandy loam, which, according to Shaw (1937), is high in Fe content, was investigated. It did not behave like the Aiken, but was similar to the other soils.

Second croppings show a certain increase in fertility in the top parts of the columns of most soils. This can be attributed to breakdown of the chemical after 60 days. In the instances where the chemical was presumably equally distributed, not being fixed, this increase in fertility in the top parts of the columns may indicate a certain amount of hydrolysis occurring as the chemical solution gets into contact with the soil. This is very clear in Hanford loam.

The test of second croppings showed very poor growth in Yolo clay loam and "Yolo clay loam, nitrate free" series. No explanation is offered, for in the toxicity series 680 p.p.m. of maleic hydrazide were inactivated in Yolo clay loam in a period of 60 days, whereas in the percolation test reported here 220.0 p.p.m. were not. Plant leaves showed typical growth inhibition and anthocyanin pigmentation.

Increasing the concentrations of herbicide added to Aiken clay loam increased further the quantity of soil sterilized, indicating an adsorption mechanism for maleic hydrazide fixation. The fact is that 220.0 p.p.m. sterilized 30 cm, 440.0 p.p.m. sterilized 50 cm, and 880.0 p.p.m. sterilized 70 cm. Thus, doubling the concentration after the first 220.0 p.p.m. increased the sterilized area by two thirds the original amount, and doubling still further increased the sterility in about the same proportion.

LEACHING EXPERIMENTS

The two soils used were Yolo fine sandy loam and Aiken clay loam. The method was similar to that used in the study of the distribution of the chemical. After being wetted with maleic hydrazide solution, the soil columns respectively were leached with 2,500 and 1,500 cc of water. The results appear in tables 17 and 18.

It is clear that water alone can displace maleic hydrazide in the soil columns. Large quantities are needed, but displacement is possible even in the Aiken clay loams that are able to fix the herbicide on their clay colloid. It was shown that by using 200 and 300 surface cm of water, maleic hydrazide could be moved lower down and clear out of a 100-cm-long column of Aiken clay loam. Worth noting is the fact that to bring to field capacity these columns of soil, 1,500 cc of water are needed. The term "surface cm of water" is used here in the sense given to it by Crafts (1935). It indicates the equivalent of water added in cm on top of the column, and it determines the total depth of soil that could be brought to field capacity by the quantity of water added. It is evident that the same number of "surface cm of water" for different soils may be equivalent to varying depths of moistening.

The fact that the top fractions of the Yolo fine sandy loam showed such an increase in fertility (15.4 gm against 6.7 gm for the check) when 2,500 cc of water—for instance, 150 surface cm—had passed through, indicated a fairly rapid breakdown of the chemical, probably through hydrolysis. This hydrolytic effect may be similar to that of CaCN in soils. Water alone does not decompose maleic hydrazide. This fact is supported by the water-culture experiments in which no apparent inactivation occurred.

The hydrolysis of maleic hydrazide in soils—if it is such—seems repressed by large quantities of KH_2PO_4 in Aiken soils, at least as reported in this paper.

After 60 days the unleached column showed some inhibition in the top 10 cm fraction, indicating a difference in behavior when such large quantities of water are in contact with the chemical compound in the soil. This increase in yield did not occur in the same proportion in the Aiken clay loam, where 1,500 cc of water were made to percolate through the column after the addition of maleic hydrazide.

The leachates from these columns were collected in 350.0 cc increments, and one-week-old Kanota oats, which were germinated in quartz sand, were transplanted and grown in these solutions. Checks of complete Hoagland solution and distilled water were set up simultaneously. Results correlated the biological assays (plates 3 and 4). Toxicity was present only in the Yolo-soil solutions, where the second leaf growth was inhibited, and where anthocyanin

pigmentation was apparent. After 30 days the plants had not died, and fresh and dry weights are shown in table 7.

The surprising fact that root growth was inversely proportional to shoot development where maleic hydrazide was present was later noticed in the toxicity series using water culture solutions. Roots were stunted and had developed laterals while the shoots kept on developing. When the shoot growth was completely inhibited, roots lengthened, but no laterals appeared. Actual values are shown in table 8.

Measurements of leaf elongation over the 30-day period indicated that at 5.0 p.p.m., the first and second leaves steadily grew faster than the controls, the third leaf lagged, and the fourth leaf never developed. The values recorded are shown in table 9.

Subsequent investigations with water cultures using 0.0, 0.5, 1.0, 2.5, 10.0, and 20.0 p.p.m. maleic hydrazide, nutrient culture solution basis, and the method described previously, produced the results that are shown in table 10.

As these values show, 0.5 and 1.0 p.p.m. maleic hydrazide actually acted as a stimulant for both roots and shoots. Again, elongation of roots at concentrations where inhibition occurred was in inverse relation to shoot elongation, as shown by table 11.

CONCLUSIONS

From the studies reported in this paper, maleic hydrazide appears to be a "unique growth regulant." Its behavior in soils is not similar to that of any herbicide whose soil relations have been studied. There seems to be no simple relation between toxicity and soil characteristics among the 11 soils studied.

Toxicity was highest and inactivation slowest in Arbuckle clay loam, 15.0 p.p.m. being toxic originally and 340.0 p.p.m. still causing complete sterilization five months later. Sterility was obtained at 140.0 p.p.m. in four soils. This was the least degree of toxicity in the original tests. Inactivation was fastest in Aiken clay loam, where 680.0 p.p.m. were not toxic three months later. In Yolo fine sandy loam, 5,000 p.p.m. were still inhibiting all growth seven months after application.

These soils were kept moist during crop growth but dry between crops. The greenhouse was heated, so the temperatures were fairly constant and the soils were under what can be termed "warm" conditions throughout.

Percolation experiments showed that in soils where anion exchange is predominant—for instance, Aiken clay loam—maleic hydrazide was held to the clay component, while it moved freely with the soil solution in all the other soils studied.

Leaching experiments showed that the chemical could be displaced downward, but relatively large quantities of water were required.

Schoene and Hoffman (1949) mentioned that "applied to the soil as a drench much more chemical was found necessary to inhibit growth of tomato plants than when applied as a spray, indicating that entry through the leaves is more rapid than through the roots." While this statement may hold true for tomatoes, we can say that this was not found when oats were grown in California soils. As low as 15.0 p.p.m. were toxic in some soils and in water cultures 5.0 p.p.m. showed inhibiting effects on oats. The rate of absorption also was

faster in the water culture solutions, where young oats showed toxicity signs four days after transplanting, while plants of barley (20 days old) leaf-sprayed, showed clear, visible signs of toxicity only 15 days after treatment.

The Naugatuck Chemical Division (1949) suggested the use of six pounds of 30 per cent diethanolamine salt in 100 gallons of water, to retard grasses in general. This is 0.24 per cent salt basis. In the greenhouse tests, selectivity was obtained with a 0.2 per cent salt basis solution (Crafts and Currier, 1950).

As far as direct applications to the soil are concerned, a 0.2 per cent solution—for instance, 2,000 p.p.m.—in some of the soils we have studied would probably inhibit completely all new growth for at least 30 days. A 25 cc volume of a 2,000 p.p.m. solution (average of amounts sprayed on foliage) would be equivalent to 100.0 p.p.m. applied to the soil in any of our toxicity determinations.

It is possible and probable that older plants would react differently from seedlings where root absorption is concerned. Crafts, Currier, and Day (1950) showed that toxicity to sprayed plants was related to age of the plants.

The results obtained in these experiments tend to confirm the findings of Crafts, Currier, and Day (1950) that maleic hydrazide was translocated, and that when absorbed by the plant it does not break down rapidly. No recovery was observed in any instance in a 30-day period, in plants that had absorbed some chemical and showed growth inhibition signs.

The observations of Currier and Crafts (1950) and Naylor and Davis (1949) that anthocyanin pigmentation was an apparent sign of maleic hydrazide toxicity on treated plants were also true here when the chemical was absorbed through the roots.

Broad-leaved plants at the germinating stage were not more resistant than oats, and it is difficult to draw any conclusion for this part of the experiment.

The preceding discussion shows clearly that maleic hydrazide residues would not constitute a problem in most California soils. Leaching through precipitation may be effective. There are indications that this chemical decomposes fairly rapidly under moist, warm conditions, and may act as a fertilizer.

These greenhouse experiments also show that maleic hydrazide can sterilize the soil against plant growth if used in large enough quantities. However, it decomposes too readily under the conditions mentioned to be considered an effective temporary soil sterilant.

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TABLE 1

FRESH WEIGHTS OF KANOTA OAT PLANTS GROWN IN YOLO FINE SANDY LOAM AT VARIOUS CONCENTRATIONS OF MALEIC HYDRAZIDE
(Values are averages of four replicates)

Concentration of maleic hydrazide in p.p.m. (air dry soil basis)	Fresh weights of plants grown in Yolo fine sandy loam				
	First crop	Second crop	Third crop	Fourth crop	Fifth crop
	(gm)	*(gm)*	*(gm)*	*(gm)*	*(gm)*
0.0	8.7	5.1	5.5	4.5	5.9
1.0	8.6	5.5	6.4	4.6	6.5
10.0	8.2	6.0	6.8	4.9	6.4
100.0	0.0	11.7	8.5	4.5	6.6
1,000.0	0.0	0.0	5.2	12.6	9.3
5,000.0	0.0	0.0	0.0	0.0	0.0
10,000.0	0.0	0.0	0.0	0.0	0.0

TABLE 2

TOXICITY OF MALEIC HYDRAZIDE IN SOME CALIFORNIA SOILS ARRANGED IN ORDER OF INCREASING CLAY CONTENT
(Values are averages of three replicates)

Soil	Sterility obtained at:
	(p.p.m.)
Yolo fine sandy loam	80.0
Hanford loam	80.0
Aiken clay loam	140.0
Yolo clay loam	220.0
Stockton adobe clay	140.0

TABLE 3

TOXICITY OF MALEIC HYDRAZIDE IN 10 CALIFORNIA SOILS, ARRANGED IN ORDER OF INCREASING FERTILITY
(Values are averages of three replicates)

Soil	Original crop yield of control	Sterility obtained at:		
		First crop	Second crop	Third crop
	(fresh wt, gm)	*(p.p.m.)*	*(p.p.m.)*	*(p.p.m.)*
Arbuckle clay loam	0.8	15.0	80.0	340.0
Aiken clay loam	2.7	140.0	higher than 680.0	higher than 680.0
Rocklin fine sandy loam	2.7	140.0	680.0	680.0
Stockton adobe clay	3.9	140.0	490.0	higher than 680.0
Sierra fine sandy loam	4.0	80.0	higher than 680.0	higher than 680.0
Hanford loam	5.7	80.0	220.0	680.0
Yolo adobe clay	6.6	140.0	340.0	680.0
Yolo fine sandy loam	7.5	80.0	490.0	680.0
Hanford fine sandy loam	8.4	40.0	490.0	680.0
Yolo clay loam	8.9	220.0	higher than 680.0	higher than 680.0

TABLE 4

Toxicity of Maleic Hydrazide in Some California Soils Arranged in Order of Increasing pH Reaction
(Values are averages of three replicates)

Soil	Reaction	Sterility obtained at: First crop	Sterility obtained at: Second crop
		(*p.p.m.*)	(*p.p.m.*)
Sierra fine sandy loam	Moderately acid	80.0	higher than 680.0
Aiken clay loam	Slightly acid	140.0	higher than 680.0
Arbuckle clay loam	Neutral	15.0	80.0
Stockton adobe clay	Basic	140.0	490.0

TABLE 5

Toxicity of Maleic Hydrazide in Some California Soils Arranged in Order of Increasing Water-Holding Capacity at Their Saturation Point
(Values are averages of three replicates)

Soil	Water	Sterility obtained at: First crop	Sterility obtained at: Second crop
	(*per cent*)	(*p.p.m.*)	(*p.p.m.*)
Sierra fine sandy loam	13.5	80.0	higher than 680.0
Yolo fine sandy loam	15.0	80.0	490.0
Aiken clay loam	21.3	140.0	higher than 680.0
Yolo clay loam	30.0	220.0	higher than 680.0
Stockton adobe clay	32.0	140.0	490.0

TABLE 6

FRESH WEIGHTS OF DIFFERENT PLANT INDICATORS GROWN IN YOLO CLAY LOAM AT VARIOUS CONCENTRATIONS OF MALEIC HYDRAZIDE
(Values are results of first cropping)

Indicator plant*	Concentration of maleic hydrazide in Yolo clay loam, p.p.m. air dry soil									
	0.0	5.0	15.0	40.0	80.0	140.0	220.0	340.0	490.0	680.0
	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)
Bluegrass (10) (*Poa annua*)	0.4	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carrots (10)	4.2	4.2	†	†	0.0	0.0	0.0	0.0	0.0	0.0
Cotton (2)	5.2	1.7	1.8	0.8	†	†	0.0	0.0	0.0	0.0
Crabgrass (10) (*Digitaria* sp.)	8.5	7.5	3.1	4.2	3.1	0.0	0.0	0.0	0.0	0.0
Flax (10)	4.4	4.5	4.1	†	†	†	0.0	0.0	0.0	0.0
Oats (10)	8.9	8.6	7.4	1.5	0.7	0.0	0.0	0.0	0.0	0.0
Peas (3)	14.5	12.9	13.7	3.6	†	†	0.0	0.0	0.0	0.0
Sugar beets (10)	10.1	8.7	1.1	1.0	0.5	†	†	†	†	†
Sunflower (2)	16.6	16.8	1.3	2.1	†	†	†	†	†	†
Watergrass (10) (*Echinocloa Crusgalli*)	3.3	4.3	†	†	†	0.0	0.0	0.0	0.0	0.0
Watermelons (2)	6.3	9.7	1.5	0.9	0.8	0.7	0.0	0.0	0.0	0.0

* Figures in parentheses indicate number of plants harvested.
† Germination occurred normally, but subsequent growth was inhibited.

TABLE 7

FRESH AND DRY WEIGHTS OF SHOOTS AND ROOTS OF FIVE KANOTA OAT PLANTS GROWN IN SOIL LEACHATES AND CULTURE SOLUTION*

Solution	Fresh weights			Dry weights		
	Roots	Shoots	Total	Roots	Shoots	Total
	(*gm*)	(*gm*)	(*gm*)	(*gm*)	(*gm*)	(*gm*)
Aiken soil:						
First increase	5.6	2.1	7.7	0.45	0.4	0.95
Second increase	4.6	1.4	6.0	0.35	0.4	0.75
Third increase	3.7	1.2	4.9	0.3	0.3	0.60
Yolo soil:						
First increase	1.6	0.7	2.3	0.2	0.25	0.45
Second increase	1.4	0.8	2.2	0.15	0.3	0.45
Third increase	1.3	1.0	2.3	0.15	0.3	0.45
Hoagland solution	19.7	13.6	33.3	1.4	3.35	4.75
Distilled water	3.2	1.0	4.2	0.2	0.3	0.5

* Yolo soil solution contained displaced maleic hydrazide from leaching experiments.

TABLE 8

Fresh Weights of Shoots and Roots of Five Kanota Oat Plants Grown in Three Nutrient Levels of Water Culture Solutions Containing Various Quantities of Maleic Hydrazide

Maleic hydrazide in p.p.m. (culture solution basis)	0.5 H		1.0 H		2.0 H	
	Roots	Shoots	Roots	Shoots	Roots	Shoots
	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)
0.0	15.7	10.9	23.1	26.9	19.7	33.0
5.0	1.6	9.9	1.2	5.2	1.7	1.7
15.0	0.9	1.1	0.8	1.3	1.5	1.9
40.0	0.8	0.6	0.7	0.4	0.3	1.1

TABLE 9

Length of Leaves of Kanota Oats Growing in Water Culture Solutions Containing Maleic Hydrazide Three, Six, and Ten Days after Transplanting

	Number of days after transplanting								
	Three			Six			Ten		
	Concentration of maleic hydrazide								
	0.0	5.0	15.0	0.0	5.0	15.0	0.0	5.0	15.0
First leaf (*cm*)	12.0	13.5	13.0	12.0	14.0	13.0	12.0	14.0	13.0
Second leaf (*cm*)	7.0	9.0	7.0	18.0	21.0	14.0	22.0	22.0	14.0
Third leaf (*cm*)	8.0	4.0	0.0	23.0	21.0	0.0	35.0	21.0	0.0

TABLE 10

Fresh Weights of Shoots and Roots of Five Kanota Oat Plants Grown in Hoagland Complete Solution with Various Concentrations of Maleic Hydrazide

	Concentration maleic hydrazide, p.p.m., culture solution basis						
	0.0	0.5	1.0	2.5	5.0	10.0	20.0
	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, mg*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)
Roots	20.0	26.1	23.6	16.0	5.0	1.2	0.8
Shoots	28.3	29.4	30.1	25.8	9.5	2.5	1.4
Total	48.3	55.5	53.7	41.8	14.5	3.7	2.2

TABLE 11

Length of Shoots and Roots of Kanota Oat Plants Grown in Hoagland Complete Culture Solution Containing Maleic Hydrazide

(Values are averages of five plants)

	Concentration maleic hydrazide, p.p.m., culture solution basis						
	0.0	0.5	1.0	2.5	5.0	10.0	20.0
	(*length, cm*)	(*length, cm*)	(*length, cm*)	(*length, cm*)	(*length, cm*)	(*length, cm*)	(*length, cm*)
Roots	16.0	22.0	16.0	14.0	5.0	13.0	13.0
Shoots	32.0	44.0	35.0	43.0	39.0	15.0	13.0

TABLE 12

FRESH WEIGHTS AND HEIGHTS OF SHOOTS OF 10 KANOTA OAT PLANTS GROWN IN 11 CALIFORNIA SOILS CONTAINING VARYING CONCENTRATIONS OF MALEIC HYDRAZIDE

(Values are averages of three replicates)

Concentration maleic hydrazide	First crop		Second crop		Third crop		Fourth crop	
	Height	Weight	Height	Weight	Height	Weight	Height	Weight
(p.p.m.)	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*
	Yolo fine sandy loam							
0.0	30.0	7.3	21.0	4.3	27.0	5.2	22.0	5.1
5.0	27.0	5.9	28.0	5.5	26.0	4.9	21.0	4.4
15.0	13.0	2.5	30.0	8.4	25.0	5.3	19.0	4.8
40.0	6.0	0.4	34.0	8.6	28.0	5.5	23.0	5.0
80.0	0.0	0.0	35.0	8.1	28.0	6.1	21.0	5.1
140.0	0.0	0.0	30.0	8.1	31.0	7.7	23.0	5.0
220.0	0.0	0.0	20.0	3.9	32.0	9.4	26.0	5.7
340.0	0.0	0.0	13.0	2.4	35.0	10.5	27.0	7.8
490.0	0.0	0.0	0.0	0.0	13.0	4.7	32.0	8.0
680.0	0.0	0.0	0.0	0.0	13.0	0.6	38.0	11.8
	Yolo clay loam							
0.0	27.0	8.9	27.0	6.2	32.0	7.3	....	....
5.0	24.0	8.6	32.0	6.3	32.0	7.0	....	....
15.0	20.0	7.4	36.0	9.2	32.0	7.8	....	....
40.0	6.0	1.5	42.0	13.1	36.0	9.0	....	....
80.0	10.0	0.7	41.0	12.9	34.0	9.0	....	....
140.0	0.0	0.0	39.0	14.1	39.0	10.1	....	....
220.0	0.0	0.0	40.0	14.3	37.0	10.1	....	....
340.0	0.0	0.0	32.0	11.2	44.0	13.8	....	....
490.0	0.0	0.0	28.0	7.5	38.0	15.6	....	....
680.0	0.0	0.0	10.0	1.8	45.0	15.9	....	....
	Yolo adobe clay							
0.0	27.0	6.6	18.0	3.6	25.0	4.7	....	....
5.0	29.0	7.3	20.0	3.9	25.0	4.6	....	....
15.0	29.0	7.2	21.0	4.1	23.0	4.9	....	....
40.0	25.0	6.0	22.0	4.2	23.0	4.8	....	....
80.0	11.0	2.1	25.0	7.3	24.0	4.7	....	....
140.0	0.0	0.0	34.0	8.0	26.0	4.9	....	....
220.0	0.0	0.0	34.0	8.4	34.0	6.2	....	....
340.0	0.0	0.0	0.0	0.0	36.0	11.3	....	....
490.0	0.0	0.0	0.0	0.0	14.0	4.9	....	....
680.0	0.0	0.0	0.0	0.0	0.0	0.0	....	....
	Hanford fine sandy loam							
0.0	26.0	8.4	33.0	9.1	34.0	9.2	25.0	6.7
5.0	21.0	5.8	35.0	10.4	35.0	9.5	24.0	6.8
15.0	9.0	1.1	35.0	11.6	36.0	10.4	25.0	6.8
40.0	0.0	0.0	35.0	11.8	37.0	10.0	26.0	7.6
80.0	0.0	0.0	33.0	9.3	38.0	12.0	26.0	7.2
140.0	0.0	0.0	26.0	6.6	39.0	11.6	28.0	8.3
220.0	0.0	0.0	13.0	3.4	37.0	10.9	29.0	8.4
340.0	0.0	0.0	7.0	0.9	16.0	7.4	28.0	9.6
490.0	0.0	0.0	0.0	0.0	17.0	3.5	28.0	9.4
680.0	0.0	0.0	0.0	0.0	7.0	1.1	18.0	6.5

TABLE 12—*Continued*

Concentration maleic hydrazide	First crop		Second crop		Third crop		Fourth crop	
	Height	Weight	Height	Weight	Height	Weight	Height	Weight
(*p.p.m.*)	(*cm*)	(*gm*)	(*cm*)	(*gm*)	(*cm*)	(*gm*)	(*cm*)	(*gm*)
	Hanford loam							
0.0	24.0	5.7	33.0	6.4	31.0	6.5	25.0	6.1
5.0	12.0	2.0	35.0	7.1	35.0	7.2	27.0	6.0
15.0	8.0	1.1	34.0	7.3	35.0	8.0	27.0	7.0
40.0	4.0	0.2	35.0	6.6	35.0	7.8	28.0	6.7
80.0	0.0	0.0	30.0	6.2	34.0	9.1	29.0	6.4
140.0	0.0	0.0	15.0	3.2	35.0	9.4	29.0	7.0
220.0	0.0	0.0	0.0	0.0	20.0	9.3	31.0	8.5
340.0	0.0	0.0	0.0	0.0	12.0	3.4	30.0	8.8
490.0	0.0	0.0	0.0	0.0	10.0	0.9	35.0	9.0
680.0	0.0	0.0	0.0	0.0	4.0	0.0	28.0	8.6
	Aiken clay loam							
0.0	16.0	2.7	13.0	2.6	18.0	2.3	....	....
5.0	17.0	3.0	13.0	2.6	17.0	2.3	....	....
15.0	17.0	3.1	16.0	2.8	19.0	2.4	....	....
40.0	12.0	3.0	21.0	3.6	18.0	2.5	....	....
80.0	8.0	0.7	22.0	4.3	20.0	2.7	....	....
140.0	0.0	0.0	21.0	3.9	21.0	3.0	....	....
220.0	0.0	0.0	24.0	4.1	20.0	3.1	....	....
340.0	0.0	0.0	16.0	3.1	20.0	3.7	....	....
490.0	0.0	0.0	22.0	3.9	22.0	4.1	....	....
680.0	0.0	0.0	13.0	2.3	21.0	4.4	....	....
	Arbuckle clay loam							
0.0	12.0	0.8	30.0	8.2	20.0	4.1	23.0	4.0
5.0	4.0	0.3	28.0	6.2	28.0	5.5	24.0	3.7
15.0	0.0	0.0	20.0	3.1	32.0	8.3	28.0	4.8
40.0	0.0	0.0	10.0	0.8	27.0	5.5	28.0	7.5
80.0	0.0	0.0	0.0	0.0	10.0	3.5	31.0	6.7
140.0	0.0	0.0	0.0	0.0	15.0	3.5	38.0	10.5
220.0	0.0	0.0	0.0	0.0	12.0	1.1	32.0	8.3
340.0	0.0	0.0	0.0	0.0	0.0	0.0	34.0	2.1
490.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
680.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Stockton adobe clay							
0.0	21.0	3.9	18.0	3.2	22.0	3.3	....	....
5.0	22.0	3.6	20.0	3.5	23.0	3.1	....	....
15.0	23.0	3.7	20.0	3.5	24.0	3.5	....	....
40.0	25.0	4.4	25.0	4.1	30.0	4.7	....	....
80.0	3.0	0.2	27.0	6.1	36.0	4.7	....	....
140.0	0.0	0.0	30.0	7.9	36.0	7.3	....	....
220.0	0.0	0.0	33.0	8.1	37.0	7.2	....	....
340.0	0.0	0.0	16.0	7.2	35.0	9.6	....	....
490.0	0.0	0.0	0.0	0.0	39.0	9.6	....	....
680.0	0.0	0.0	0.0	0.0	39.0	9.6	....	....

TABLE 12—*Concluded*

Concentration maleic hydrazide	First crop		Second crop		Third crop		Fourth crop	
	Height	Weight	Height	Weight	Height	Weight	Height	Weight
(*p.p.m.*)	(*cm*)	(*gm*)	(*cm*)	(*gm*)	(*cm*)	(*gm*)	(*cm*)	(*gm*)
	Egbert loam*							
0.0	35.0	9.9	32.0	9.3	25.0	6.2		
5.0	36.0	10.6	32.0	7.8	24.0	4.7		
15.0	37.0	11.1	33.0	9.9	30.0	8.0		
40.0	38.0	11.0	36.0	12.1	29.0	8.2		
80.0	5.0	0.3	37.0	12.1	31.0	9.3		
140.0	0.0	0.0	37.0	15.7	27.0	6.3		
220.0	0.0	0.0	26.0	8.9	34.0	7.0		
340.0	0.0	0.0	10.0	0.8	36.0	9.0		
490.0	0.0	0.0	0.0	0.0	10.0	1.3		
680.0	0.0	0.0	0.0	0.0	0.0	0.0		
	Rocklin fine sandy loam							
0.0	17.0	2.7	20.0	3.3	20.0	3.8	20.0	4.3
5.0	18.0	2.5	20.0	3.5	20.0	3.7	21.0	3.8
15.0	18.0	2.7	19.0	3.4	21.0	3.7	20.0	4.0
40.0	18.0	2.7	22.0	4.1	24.0	3.9	21.0	4.0
80.0	0.0	0.0	28.0	4.9	25.0	4.4	23.0	4.2
140.0	0.0	0.0	29.0	5.0	26.0	4.6	23.0	4.4
220.0	0.0	0.0	23.0	4.2	26.0	4.7	25.0	4.8
340.0	0.0	0.0	12.0	1.6	31.0	4.8	24.0	4.8
490.0	0.0	0.0	10.0	1.0	24.0	4.5	24.0	5.1
680.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.6
	Sierra fine sandy loam							
0.0	23.0	4.0	24.0	4.4	24.0	4.9		
5.0	23.0	4.1	24.0	4.3	27.0	4.8		
15.0	22.0	3.9	26.0	4.3	30.0	5.3		
40.0	22.0	3.8	30.0	4.8	29.0	4.7		
80.0	0.0	0.0	27.0	6.8	33.0	5.9		
140.0	0.0	0.0	36.0	6.0	30.0	5.9		
220.0	0.0	0.0	34.0	5.5	35.0	6.8		
340.0	0.0	0.0	30.0	2.0	32.0	7.4		
490.0	0.0	0.0	15.0	1.3	16.0	7.9		
680.0	0.0	0.0	12.0	1.1	18.0	4.3		

* Washed with excess water.

TABLE 13

FRESH WEIGHTS AND HEIGHTS OF 10 KANOTA OAT PLANTS GROWN IN COLUMNS OF AIKEN CLAY LOAM CONTAINING VARYING P.P.M. OF MALEIC HYDRAZIDE

Depth	Aiken clay loam									
	First crop						Second crop			
	220.0 p.p.m.		440.0 p.p.m.		880.0 p.p.m.		440.0 p.p.m.		880.0 p.p.m.	
	Height	Weight	Height	Weight	Height	Weight	Height	Weight	Height	Weight
(cm)	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*
0.0–10.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0	1.5	0.0	0.0
10.0–20.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	3.4	0.0	0.2
20.0–30.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0	3.3	6.0	0.3
30.0–40.0	10.0	1.6	0.0	0.0	0.0	0.0	14.0	3.2	15.0	2.2
40.0–50.0	13.0	2.0	4.0	0.4	0.0	0.0	15.0	3.2	10.0	1.3
50.0–60.0	13.0	2.3	17.0	1.7	0.0	0.0	16.0	3.4	14.0	2.7
60.0–70.0	14.0	2.8	16.0	1.8	0.0	0.0	15.0	2.7	14.0	2.4
70.0–80.0	14.0	2.7	17.0	1.7	17.0	2.1	15.0	3.4	18.0	3.4
80.0–90.0	15.0	2.7	20.0	1.7	14.0	2.0	15.0	3.0	17.0	3.2
90.0–100.0	11.0	3.0	20.0	1.8	16.0	2.2	16.0	3.4	13.0	2.7
Checks	16.0	2.8	19.0	2.1	15.0	2.3	16.0	3.2	16.0	2.9

TABLE 14

FRESH WEIGHTS AND HEIGHTS OF 10 KANOTA OAT PLANTS GROWN IN COLUMNS OF AIKEN CLAY LOAM CONTAINING 220.0 P.P.M. MALEIC HYDRAZIDE AND ALSO UNDER CONDITIONS IN WHICH PHOSPHATE WAS ADDED BOTH BEFORE AND AFTER THE ADDITION OF MALEIC HYDRAZIDE

Depth	Aiken clay loam									
	First crop						Second crop			
	220.0 p.p.m. maleic hydrazide		Phosphate added after m.h.		Phosphate added before m.h.		Phosphate added after m.h.		Phosphate added before m.h.	
	Height	Weight	Height	Weight	Height	Weight	Height	Weight	Height	Weight
(cm)	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*
0.0–10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.0–20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.0–30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30.0–40.0	10.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40.0–50.0	13.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50.0–60.0	13.0	2.3	0.0	0.0	0.0	0.0	24.0	6.8	0.0	0.0
60.0–70.0	14.0	2.8	15.0	2.3	0.0	0.0	16.0	2.3	0.0	0.0
70.0–80.0	14.0	2.7	16.0	2.5	0.0	0.0	16.0	2.8	0.0	0.0
80.0–90.0	15.0	2.7	15.0	2.6	0.0	0.0	15.0	1.6	0.0	0.0
90.0–100.0	11.0	3.0	15.0	2.5	0.0	0.0	16.0	2.5	0.0	0.0
Checks	16.0	2.8	17.0	2.6	18.0	2.8	16.0	2.7	19.0	3.5

TABLE 15

FRESH WEIGHTS AND HEIGHTS OF 10 KANOTA OAT PLANTS GROWN IN COLUMNS OF SIERRA FINE SANDY LOAM CONTAINING 220.0 P.P.M. MALEIC HYDRAZIDE

Depth	Sierra fine sandy loam					
	First crop		Second crop		Third crop	
	Height	Weight	Height	Weight	Height	Weight
(cm)	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*
0.0–10.0	0.0	0.0	0.0	0.0	7.0	0.2
10.0–20.0	0.0	0.0	0.0	0.0	13.0	1.4
20.0–30.0	0.0	0.0	0.0	0.0	30.0	6.7
30.0–40.0	0.0	0.0	15.0	0.7	29.0	5.8
40.0–50.0	0.0	0.0	27.0	6.6	32.0	5.9
50.0–60.0	0.0	0.0	28.0	5.7	30.0	6.3
60.0–70.0	0.0	0.0	28.0	6.0	32.0	6.7
70.0–80.0	0.0	0.0	26.0	5.2	34.0	5.7
80.0–90.0	0.0	0.0	24.0	4.5	32.0	7.2
90.0–100.0	0.0	0.0	25.0	4.5	32.0	6.5
Checks	25.0	3.5	23.0	4.1	33.0	5.8

TABLE 16

FRESH WEIGHTS AND HEIGHTS OF 10 KANOTA OAT PLANTS GROWN IN COLUMNS OF SIX DIFFERENT SOILS CONTAINING 220.0 P.P.M. MALEIC HYDRAZIDE

Depth	First crop		Second crop	
	Height	Weight	Height	Weight
(*cm*)	(*cm*)	(*gm*)	(*cm*)	(*gm*)
	Aiken clay loam			
0.0–10.0	0.0	0.0	20.0	5.0
10.0–20.0	0.0	0.0	16.0	3.8
20.0–30.0	0.0	0.0	13.0	2.9
30.0–40.0	10.0	1.6	13.0	2.7
40.0–50.0	13.0	2.0	13.0	2.5
50.0–60.0	13.0	2.3	12.0	2.3
60.0–70.0	14.0	2.8	12.0	2.7
70.0–80.0	14.0	2.7	15.0	2.6
80.0–90.0	15.0	2.7	16.0	2.7
90.0–100.0	11.0	3.0	16.0	2.4
Checks	16.0	2.8	12.0	2.5
	Hanford loam			
0.0–10.0	0.0	0.0	30.0	11.1
10.0–20.0	0.0	0.0	20.0	8.1
20.0–30.0	0.0	0.0	15.0	5.2
30.0–40.0	0.0	0.0	15.0	5.8
40.0–50.0	0.0	0.0	10.0	1.8
50.0–60.0	0.0	0.0	10.0	4.1
60.0–70.0	0.0	0.0	10.0	0.4
70.0–80.0	0.0	0.0	20.0	6.1
80.0–90.0	0.0	0.0	20.0	7.1
90.0–100.0	0.0	0.0	20.0	6.8
Checks	30.0	6.2	19.0	5.6
	Stockton adobe clay			
0.0–10.0	0.0	0.0	20.0	6.3
10.0–20.0	0.0	0.0	17.0	5.1
20.0–30.0	0.0	0.0	20.0	5.2
30.0–40.0	0.0	0.0	15.0	5.0
40.0–50.0	0.0	0.0	20.0	4.8
50.0–60.0	0.0	0.0	20.0	5.0
60.0–70.0	0.0	0.0	18.0	5.1
70.0–80.0	0.0	0.0	19.0	5.1
80.0–90.0	8.0	0.9	19.0	4.8
90.0–100.0	20.0	3.0	17.0	3.5
Checks	20.0	3.3	14.0	2.8

TABLE 16—*Continued*

Depth	First crop		Second crop	
	Height	Weight	Height	Weight
(cm)	*(cm)*	*(gm)*	*(cm)*	*(gm)*
	Yolo clay loam			
0.0–10.0	0.0	0.0	5.0	0.5
10.0–20.0	0.0	0.0	10.0	1.1
20.0–30.0	0.0	0.0	10.0	0.9
30.0–40.0	0.0	0.0	10.0	1.3
40.0–50.0	0.0	0.0	6.0	0.6
50.0–60.0	0.0	0.0	8.0	0.7
60.0–70.0	0.0	0.0	8.0	0.9
70.0–80.0	0.0	0.0	14.0	2.2
80.0–90.0	0.0	0.0	11.0	2.7
90.0–100.0	0.0	0.0	14.0	1.1
Checks	33.0	8.8	20.0	4.2
	Yolo clay loam (nitrate free)			
0.0–10.0	0.0	0.0	8.0	0.6
10.0–20.0	0.0	0.0	8.0	0.8
20.0–30.0	0.0	0.0	6.0	0.5
30.0–40.0	0.0	0.0	6.0	0.3
40.0–50.0	0.0	0.0	4.0	0.2
50.0–60.0	0.0	0.0	8.0	0.8
60.0–70.0	0.0	0.0	10.0	0.8
70.0–80.0	0.0	0.0	4.0	0.4
80.0–90.0	0.0	0.0	10.0	1.1
90.0–100.0	0.0	0.0	12.0	1.6
Checks	33.0	8.8	17.0	3.9
	Yolo fine sandy loam			
0.0–10.0	0.0	0.0	13.0	2.1
10.0–20.0	0.0	0.0	25.0	9.4
20.0–30.0	0.0	0.0	22.0	7.2
30.0–40.0	0.0	0.0	20.0	6.3
40.0–50.0	0.0	0.0	18.0	5.9
50.0–60.0	0.0	0.0	15.0	6.2
60.0–70.0	0.0	0.0	25.0	10.3
70.0–80.0	0.0	0.0	25.0	9.6
80.0–90.0	0.0	0.0	10.0	1.5
90.0–100.0	0.0	0.0	25.0	7.5
Checks	33.0	7.6	20.0	4.2

TABLE 17

FRESH WEIGHTS AND HEIGHTS OF FIRST CROP OF KANOTA OATS PLANTS GROWN IN COLUMNS OF YOLO FINE SANDY LOAM CONTAINING 220.0 P.P.M. PER COLUMN WHICH WAS THEN LEACHED WITH 150 SURFACE CENTIMETERS OF WATER

Depth	Yolo fine sandy loam	
	Height	Weight
(cm)	*(cm)*	*(gm)*
0.0–10.0	38.0	15.4
10.0–20.0	36.0	10.7
20.0–30.0	28.0	7.3
30.0–40.0	26.0	5.1
40.0–50.0	25.0	4.3
50.0–60.0	28.0	4.3
60.0–70.0	28.0	4.3
70.0–80.0	25.0	4.2
80.0–90.0	0.0	0.0
90.0–100.0	0.0	0.0
Checks	28.0	6.7

TABLE 18

FRESH WEIGHTS AND HEIGHTS OF KANOTA OAT PLANTS GROWN IN COLUMNS OF AIKEN CLAY LOAM CONTAINING TWO CONCENTRATIONS OF MALEIC HYDRAZIDE THAT WAS LEACHED WITH INCREASING AMOUNTS OF WATER

Depth	Aiken clay loam					
	220.0 p.p.m. leached with 100 surface cm water		880.0 p.p.m. leached with 200 surface cm water		880.0 p.p.m. leached with 400 surface cm water	
	Height	Weight	Height	Weight	Height	Weight
(cm)	*(cm)*	*(gm)*	*(cm)*	*(gm)*	*(cm)*	*(gm)*
0.0–10.0	21.0	3.9	17.0	2.8	14.0	2.1
10.0–20.0	18.0	3.0	14.0	2.1	13.0	2.2
20.0–30.0	15.0	2.6	17.0	3.5	13.0	2.8
30.0–40.0	5.0	0.2	17.0	2.9	15.0	2.5
40.0–50.0	4.0	0.2	19.0	3.5	15.0	2.3
50.0–60.0	4.0	0.3	14.0	2.3	16.0	3.0
60.0–70.0	12.0	2.3	0.0	0.0	14.0	2.4
70.0–80.0	15.0	2.7	0.0	0.0	14.0	2.4
80.0–90.0	15.0	2.6	0.0	0.0	15.0	2.9
90.0–100.0	15.0	2.5	0.0	0.0	10.0	2.9
Checks	15.0	2.4	10.0	2.6	12.0	2.2

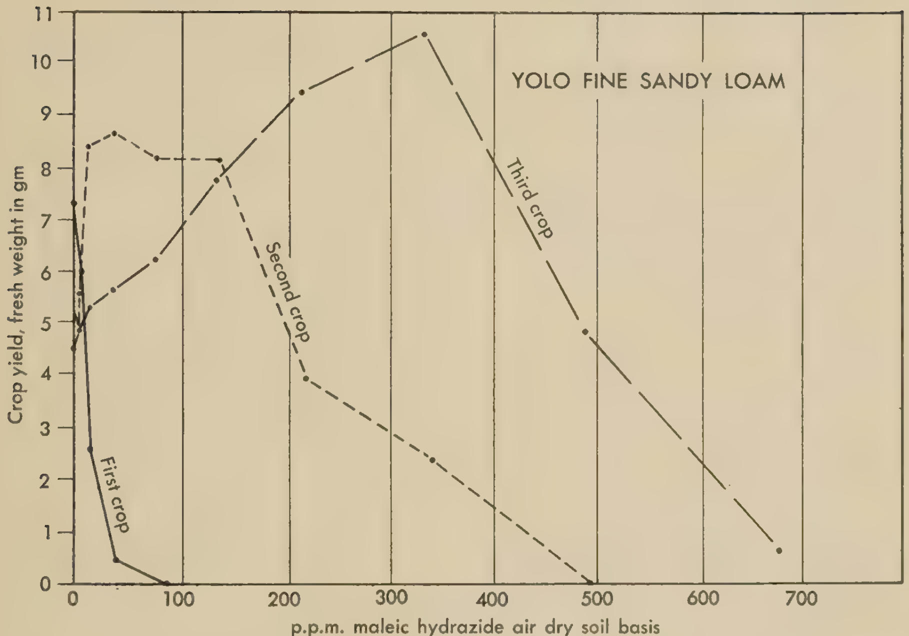

Fig. 1. Toxicity of maleic hydrazide in Yolo fine sandy loam.

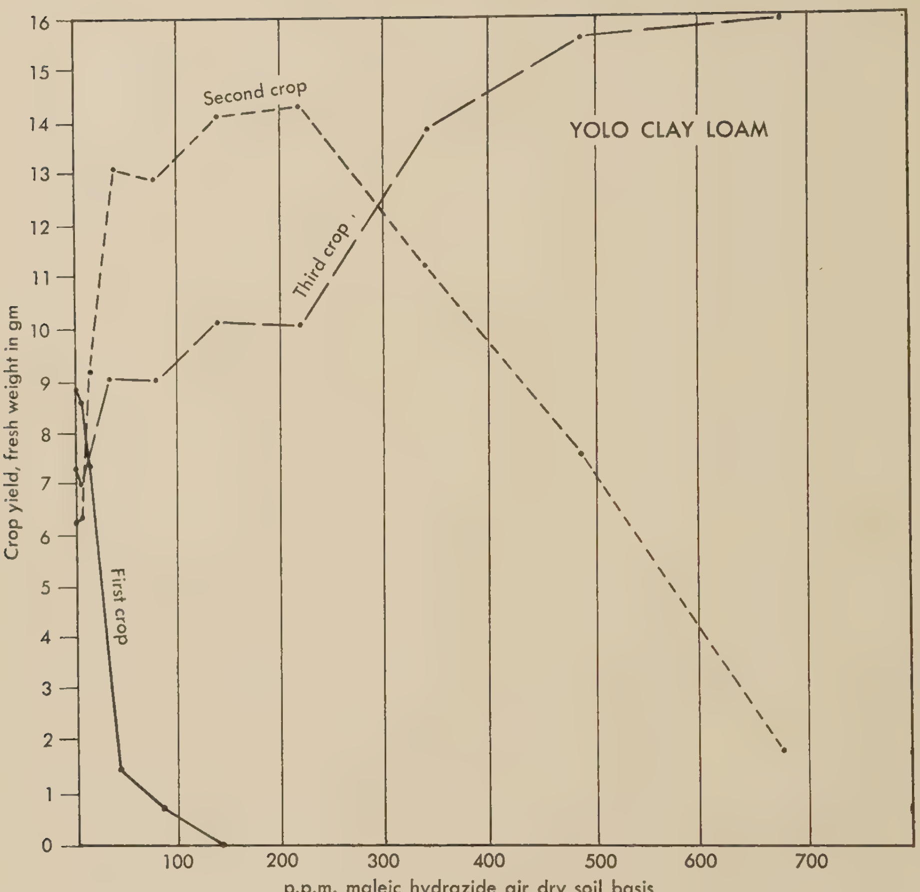

Fig. 2. Toxicity of maleic hydrazide in Yolo clay loam.

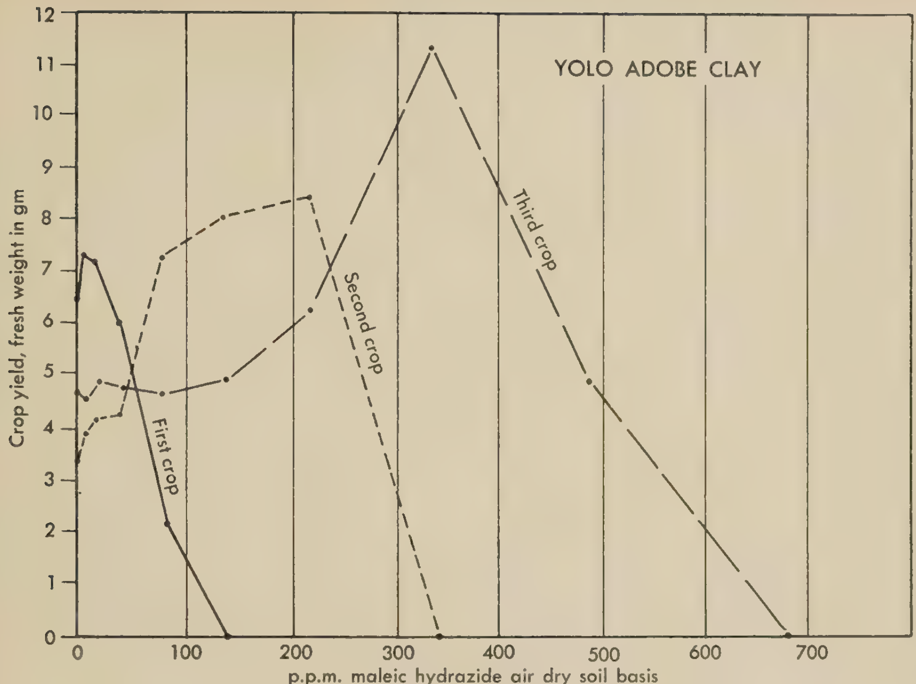

Fig. 3. Toxicity of maleic hydrazide in Yolo adobe clay.

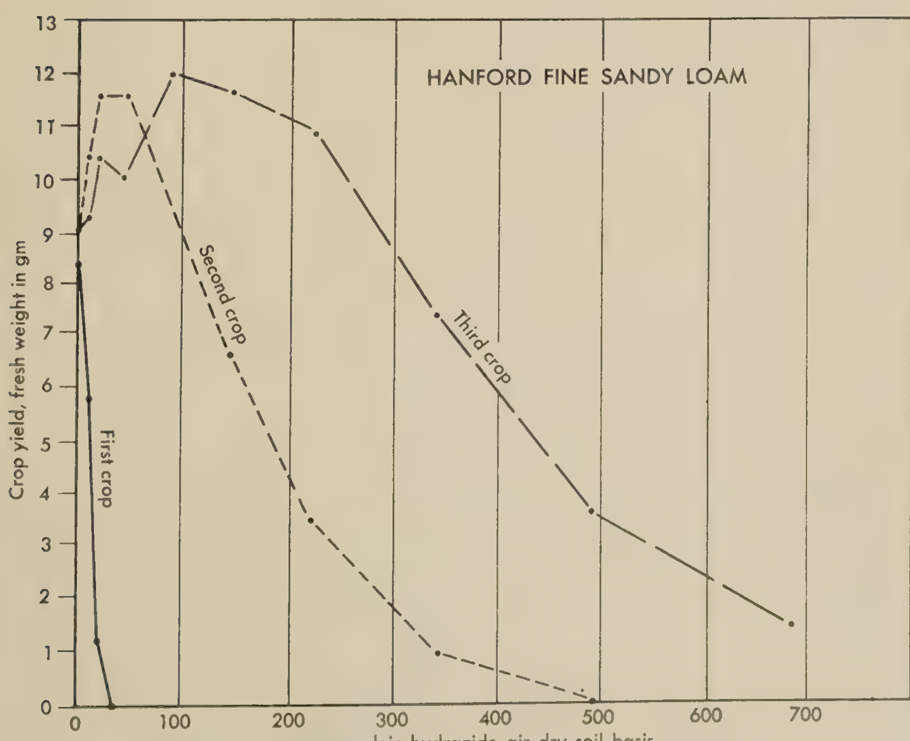

Fig. 4. Toxicity of maleic hydrazide in Hanford fine sandy loam.

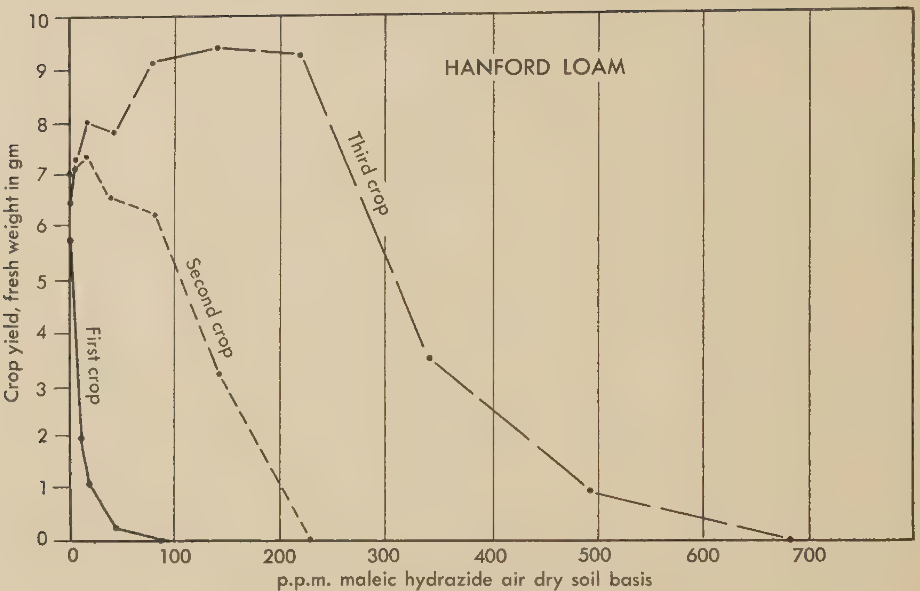

Fig. 5. Toxicity of maleic hydrazide in Hanford loam.

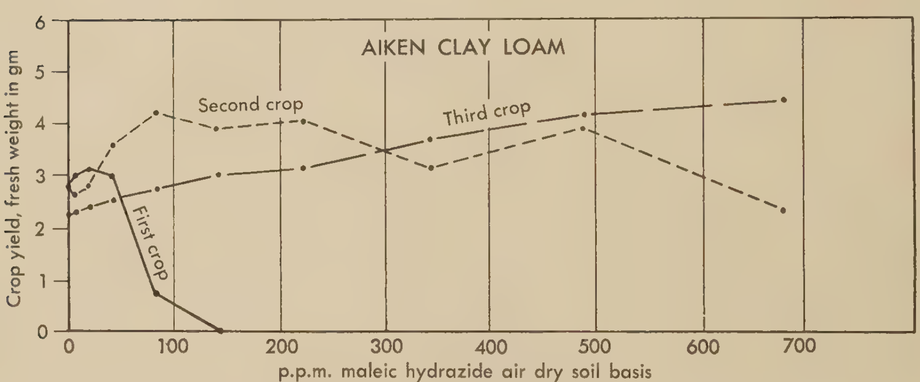

Fig. 6. Toxicity of maleic hydrazide in Aiken clay loam.

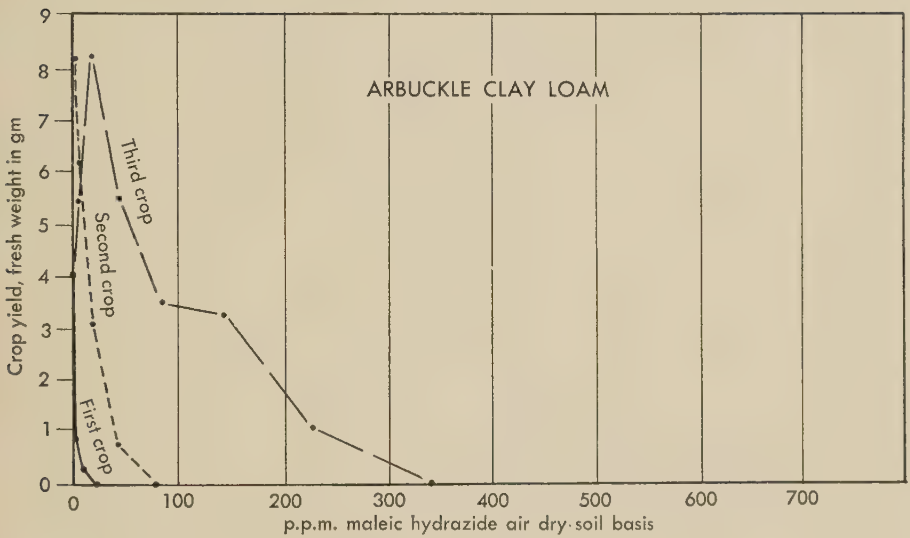

Fig. 7. Toxicity of maleic hydrazide in Arbuckle clay loam.

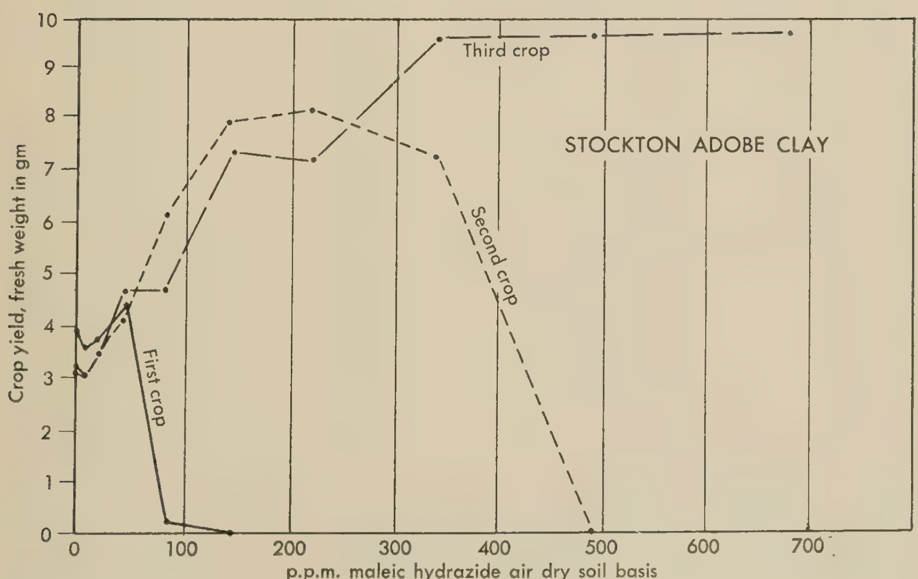

Fig. 8. Toxicity of maleic hydrazide in Stockton adobe clay.

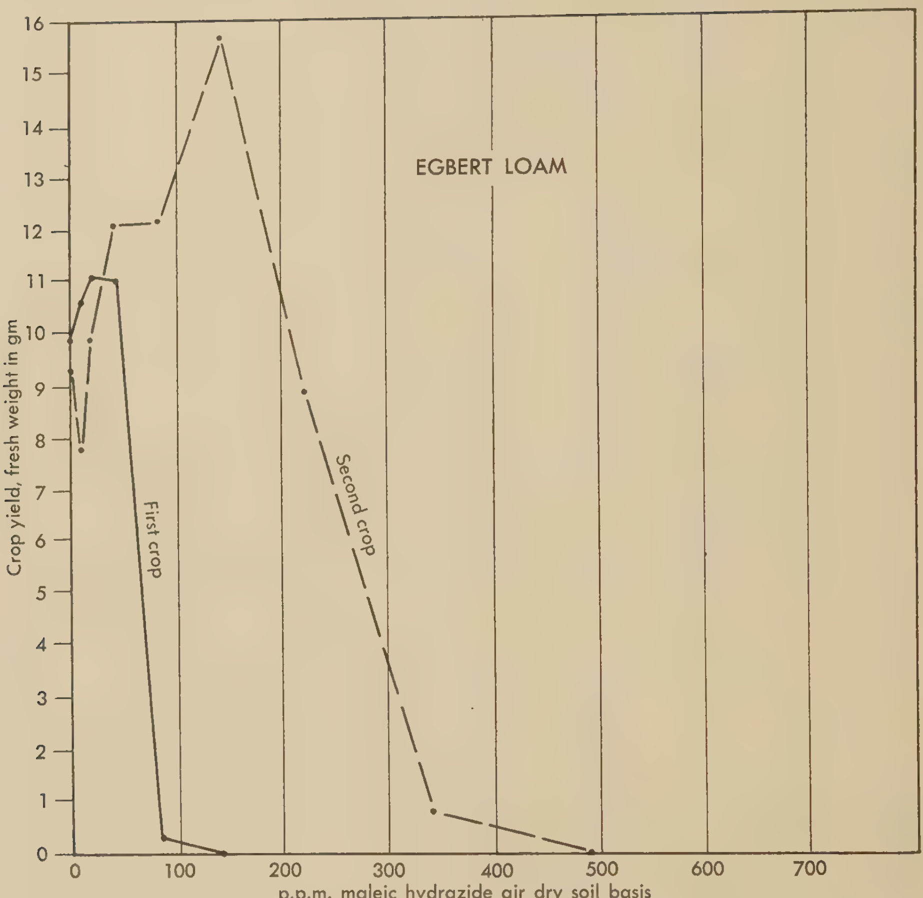

Fig. 9. Toxicity of maleic hydrazide in Egbert loam previously leached with water.

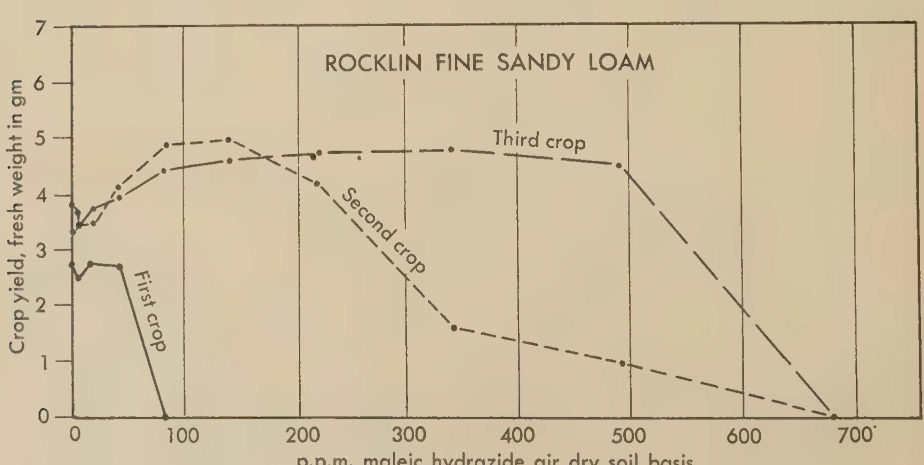

Fig. 10. Toxicity of maleic hydrazide in Rocklin fine sandy loam.

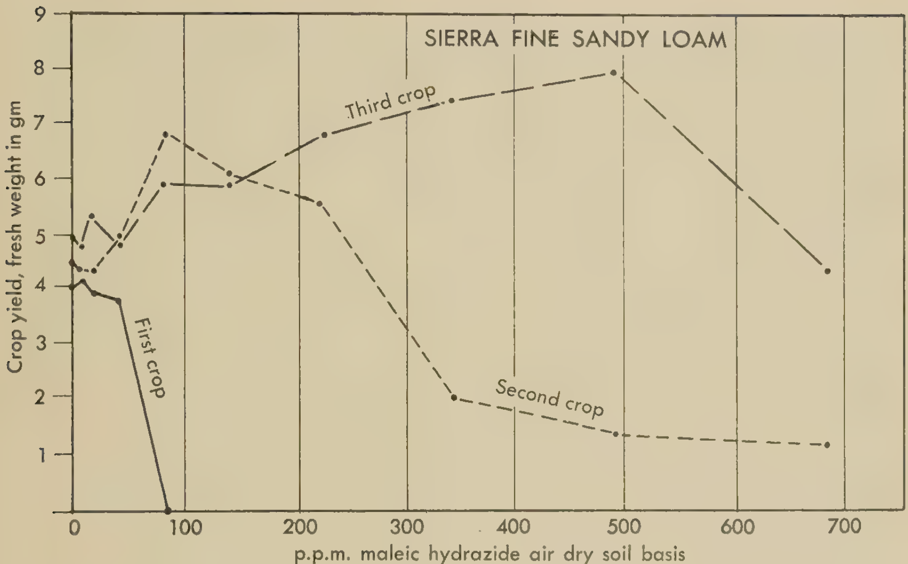

Fig. 11. Toxicity of maleic hydrazide in Sierra fine sandy loam.

Plate 1. Toxicity of maleic hydrazide in Yolo clay loam, first crop. Top to bottom: flax, peas, and crabgrass (*Digitaria* sp.). Left to right: 0.0; 5.0; 15.0; 40.0; 80.0; 140.0; 220.0; 340.0; 490.0; and 680.0 p.p.m. maleic hydrazide added, air dry soil basis.

Plate 2. Distribution of maleic hydrazide in Aiken clay loam treated with KH_2PO_4; first crop, 12 days after planting. Top: soil saturated with phosphate after addition of 220.0 p.p.m. maleic hydrazide; bottom: soil saturated with phosphate before addition of 220.0 p.p.m. maleic hydrazide. Left to right: control; 100–90; 90–80; 80–70; 70–60; 60–50; 50–40; 40–30; 30–20; 20–10; 10–0.0 cms depth.

Plate 3. Comparing growth of Kanota oats in soil and "Hoagland" solutions. Top: Aiken soil solution without maleic hydrazide; bottom: Yolo fine sandy loam soil solution containing maleic hydrazide. Right to left: Full Hoagland, distilled water, soil solutions. Note leaf length.

Plate 4. Kanota oat plants grown in soil solutions and nutrient culture solution (30 days after starting). Right to left: complete Hoagland solution; Yolo soil solution (contains maleic hydrazide); Aiken soil solution (no maleic hydrazide present); and distilled water.

TOXICITY OF PHENYL MERCURIC COMPOUNDS IN CALIFORNIA SOILS[1]

E. LEVI[2] and A. S. CRAFTS[3]

INTRODUCTION

In the spring of 1947 the Rhode Island Experiment Station announced that phenyl mercuric acetate (soluble), which had been applied to soil as a fungicide, also controlled crabgrass (*Digitaria* sp.) seedlings in lawns (1947).[4] DeFrance (1947) reported good control of crabgrass seedlings from seven applications of the commercial product, sold under the trade name of Tat-C-Lect, made at the rate of one pint of concentrate to 100 gallons of water and applied at the rate of 10 gallons per 1,000 square feet. The commercially recommended dosage is eight ounces per gallon, applied twice, five to seven days apart, at a rate of one gallon per 500 square feet.

Because crabgrass is one of the worst of lawn weeds, the commercial publicity given to its control by the phenyl mercuric compounds was very widespread. To determine the eventual toxicity of spray residues in the soil and the possibilities of ridding the soil of their effects was therefore important.

MATERIALS AND METHODS

Tests were carried out in the greenhouse to study the toxicity, distribution (percolation), and leaching of phenyl mercuric compounds in samples from four California soil series: Yolo, Aiken, Hanford, and Willows. Three compounds were studied in their effects on the soils: phenyl mercuri triethanol ammonium lactate, phenyl mercuric acetate, and phenyl mercuric hydroxide. Kanota oats were used as indicator plants.

Toxicity Tests. The method followed in these tests was first described by Crafts (1935). Several series of cultures were grown in unperforated no. 2 cans. They contained the following concentrations of phenyl mercuric compounds: 0.0, 5.0, 15.0, 40.0, 80.0, 140.0, 220.0, 340.0, 490.0, and 680.0 p.p.m., air dry soil basis.

Because of the somewhat low solubility in water of phenyl mercuric acetate, no cultures using this herbicide above 370.0 p.p.m. were set up. The amounts of chemical were taken from a stock solution, diluted to a total volume sufficient to bring the soil to its field capacity, and added in three increments to obtain more even distribution. The cans were then seeded and the soil brought regularly to its field capacity by weighing. After 30 days, the crop was cut at ground level and its fresh weight recorded. It was then returned to each individual culture. The soil, which had dried out over a period of 30 days, was pulverized, poured back into the cans on top of the dried plant material, moistened to its field capacity, and reseeded to determine any change in toxicity.

[1] Received for publication November 3, 1950.

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[4] See "Literature Cited" for citations referred to in text by author and date.

The results of the toxicity tests are shown in figures 1 to 5 and in tables 1 and 2.

Distribution Tests. Percolation tests were carried out to determine the distribution of the phenyl mercuric compounds in columns of air dry soil. The apparatus used and the method followed were first described by Crafts (1935). The amounts of herbicide added were equal to those necessary to induce a severe growth inhibition in cultures of the toxicity tests, to half, and to twice this value.

Experimental results are shown in figures 6 to 11 and in tables 3 and 4.

Leaching Tests. The apparatus used in the percolation test was also used here. After the chemical solution had percolated entirely through the soil, measured quantities of water were added to the top of these columns and allowed to leach through the soil. To columns previously receiving herbicides quantitatively equal to twice the amount necessary to inhibit growth in the original toxicity series were added 5.0, 10.0, and 20.0 "surface cms of water" (Crafts, 1949).

Figures 12 to 16 and table 5 summarize the experimental data.

DISCUSSION AND CONCLUSIONS

As can be seen in figure 1, the effect of the three different chemicals used was very similar in Yolo fine sandy loam, the acetate and hydroxide compounds being very slightly less toxic than the triethanol ammonium lactate. These differences, however, are not significant.

A study of the data on the initial toxicity run indicates that these compounds act as soil sterilants for a range of values going from 220.0 to more than 680.0 p.p.m. in the four soils studied, yet at 220.0 p.p.m., reduction in yield was considerable in all instances.

With the exception of Yolo adobe clay, which Crafts (1949) reported as acting differently from soils of its type, there is an evident relation between toxicity and clay content of the soils, as can be seen in table 6. Within the Yolo group, the toxicity can also be correlated to the fertility level of the soil, if the fresh weight of the checks is taken as an index of that soil characteristic (table 7).

Results of the percolation tests later confirmed this point, as can be seen in figures 6 to 10, where, in all instances, growth inhibition occurred in the top 10 cms of a soil column 85 cms long. It was also determined (fig. 11) that the chemical compound actually accumulated in a much smaller fraction of soil—not more than 5 cm in thickness.

The apparent discrepancy in growth in the 2.5 to 5.0 cm fraction between Yolo clay loam and Yolo fine sandy loam, shown in table 4, is due probably to the fact that 1 inch of air dry soil of a column of the last soil is approximately equivalent to 166 gm, whereas that of the first soil is only 145 gm.

Examination of figures 2 to 5 will show that by the second cropping the chemical had decomposed to such an extent in all instances that little toxicity was left in the soil, even at the highest concentrations (680.0 p.p.m.) It can also be noted that in some instances values higher than the check yields were obtained after decomposition of the chemical in the soil. These values may be

Phenyl mercuri triethanol ammonium lactate toxicity in five California soils. The concentrations used are (from right to left): 0.0, 5.0, 15.0, 40.0, 80.0, 140.0, 220.0, 340.0, 490.0, and 680.0 p.p.m. air dry soil basis. Soils from top to bottom are: Yolo adobe clay; Yolo clay loam; Yolo fine sandy loam; Hanford fine sandy loam; and Egbert loam.

due to a breakdown of the herbicide releasing ammonia—for example, the triethanol ammonium lactate salt was used—and/or may be due to the total available bases in the soil, because those bases, still in the form of undecomposed plant material, utilized in the first crop were not available immediately to the second crop.

Results of the leaching experiments (figures 12 to 16) show that water up to and including 20.0 surface cm was not able to displace the toxicant from the top layer of the soil column where it had accumulated.

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TABLE 1

FRESH WEIGHTS OF KANOTA OATS GROWN IN YOLO FINE SANDY LOAM CONTAINING VARIOUS CONCENTRATIONS OF THREE PHENYL MERCURIC COMPOUNDS
(Values are averages of two replicates)

Concentration of compound in p.p.m. (air dry soil basis)	Phenyl mercuri triethanol ammonium lactate	Phenyl mercuric hydroxide	Phenyl mercuric acetate
	(wt, gm)	*(wt, gm)*	*(wt, gm)*
0.0	9.0	9.0	9.5
5.0	9.5	10.8	10.1
15.0	9.2	10.7	9.9
40.0	8.4	10.3	8.2
80.0	7.2	7.1	7.4
140.0	5.0	4.1	4.2
220.0	0.8	1.3	3.7
340.0	0.0	0.8	0.8

TABLE 2

FRESH WEIGHTS OF KANOTA OATS GROWN IN FOUR CALIFORNIA SOILS CONTAINING VARIOUS CONCENTRATIONS OF PHENYL MERCURI TRIETHANOL AMMONIUM LACTATE
(Values are averages of two replicates)

Concentration of compound in p.p.m. (air dry soil basis)	Soils			
	Yolo fine sandy loam	Yolo clay loam	Yolo adobe clay	Hanford fine sandy loam
	First crop			
	(wt, gm)	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*
0.0	9.0	12.1	6.9	6.0
5.0	9.5	14.3	8.5	6.0
15.0	9.2	13.5	6.8	5.6
40.0	8.4	14.3	6.3	5.5
80.0	7.2	12.3	5.3	5.2
140.0	5.0	10.3	0.5	3.4
220.0	0.8	8.3	0.0	1.2
340.0	0.0	4.8	0.0	0.8
490.0	0.0	3.6	0.0	0.0
680.0	0.0	2.8	0.0	0.0
	Second crop			
	(wt, gm)	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*
0.0	6.8	9.0	3.7	6.3
5.0	5.8	9.1	4.0	5.3
15.0	6.4	9.1	3.8	5.6
40.0	6.9	11.0	4.2	5.6
80.0	8.6	12.1	4.3	6.3
140.0	9.8	12.7	6.2	8.2
220.0	8.9	13.1	5.2	8.8
340.0	8.8	10.1	4.9	8.6
490.0	7.0	10.9	3.6	7.3
680.0	6.0	11.5	2.7	6.8

TABLE 3

Fresh Weights of Kanota Oats Grown in Fractions of Columns of Five California Soils in Percolation Tests Using Phenyl Mercuric Hydroxide

Depth	Soils: Yolo fine sandy loam (p.p.m. added)			Soils: Yolo clay loam (p.p.m. added)		
	75	150	300	350	700	1400
(cm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)
0.0– 8.5	4.3	2.0	2.8	4.1	3.5	1.7
8.5–17.0	5.1	5.0	5.7	11.7	9.0	6.9
17.0–25.5	6.8	5.3	6.1	12.9	12.6	9.5
25.5–34.0	7.8	7.4	7.3	12.7	15.0	12.2
34.0–42.5	11.1	11.1	9.2	13.6	15.0	12.6
42.5–51.0	12.8	11.3	11.2	13.0	15.2	12.1
51.0–59.5	13.8	11.7	11.9	14.0	15.8	14.0
59.5–68.0	11.8	10.4	11.3	16.2	17.2	15.1
68.0–76.5	10.6	9.6	9.4	16.3	15.6	13.8
76.5–85.0	10.4	10.2	9.6	0.0	15.6	14.6
Checks	10.7	10.6	9.6	12.3	13.0	12.4

Depth	Soils: Hanford fine sandy loam (p.p.m. added)			Soils: Aiken clay loam (p.p.m. added)			Soils: Willows adobe clay (p.p.m. added)		
	50	100	200	700	1400	2800	100	200	400
(cm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)	(wt, gm)
0.0– 8.5	8.5	6.2	6.2	3.2	1.1	0.7	2.6	1.8	1.7
8.5–17.0	8.4	8.1	9.0	5.7	5.4	5.9	3.6	3.0	5.3
17.0–25.5	15.6	9.0	9.2	6.9	5.0	5.8	4.0	3.1	5.1
25.5–34.0	15.0	9.2	9.5	5.8	6.2	6.3	4.6	3.8	5.2
34.0–42.5	16.7	13.3	10.4	5.0	5.5	5.1	3.2	3.5	6.2
42.5–51.0	14.0	8.8	8.5	5.0	5.5	5.1	4.2	4.2	5.2
51.0–59.5	14.6	8.7	7.9	3.4	5.6	5.9	3.2	3.7	5.0
59.5–68.0	14.7	8.6	8.7	5.5	5.4	5.9	4.6	4.4	5.3
68.0–76.5	14.3	9.6	9.1	5.2	6.0	6.0	4.0	4.7	5.4
76.5–85.0	13.6	10.8	9.2	5.4	5.3	4.9	5.0	4.0	5.0
Checks	13.1	9.6	10.4	4.0	5.0	5.7	4.2	4.0	5.4

TABLE 4

Fresh Weights of Kanota Oats Grown in Fractions of Columns of Two California Soils in Percolation Tests Using Phenyl Mercuric Acetate

Depth	Yolo fine sandy loam (150 p.p.m. added)	Yolo clay loam (700 p.p.m. added)
(cm)	(wt, gm)	(wt, gm)
0.0– 2.5	0.3	0.0
2.5– 5.0	3.2	2.5
5.0– 7.5	4.5	4.9
7.5–10.0	4.4	5.6
10.0–12.5	4.5	5.9
Checks	6.6	6.6

TABLE 5

FRESH WEIGHTS OF KANOTA OATS GROWN IN FRACTIONS OF COLUMNS OF FIVE CALIFORNIA SOILS IN LEACHING TESTS USING PHENYL MERCURIC HYDROXIDE

Depth	Hanford fine sandy loam (columns percolated with 200 p.p.m.)			Yolo fine sandy loam (columns percolated with 300 p.p.m.)			Yolo clay loam (columns percolated with 1400 p.p.m.)			Willows adobe clay (columns percolated with 1400 p.p.m.)			Aiken clay loam (columns percolated with 2800 p.p.m.)	
	Surface water added			Surface water added			Surface water added			Surface water added			Surface water added	
	5 cm	10 cm	20 cm	5 cm	10 cm	20 cm	5 cm	10 cm	20 cm	5 cm	10 cm	20 cm	5 cm	20 cm
(cm)	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*
0.0– 8.5	3.9	2.3	4.6	1.6	0.4	3.3	0.1	0.2	2.8	0.6	1.0	1.8	0.1	0.5
8.5–17.0	8.4	9.3	7.0	5.3	5.5	5.5	7.0	8.2	13.3	4.7	3.9	3.1	4.5	5.4
17.0–25.5	10.3	11.4	8.0	7.5	5.1	6.2	7.0	13.3	12.0	5.8	4.9	2.9	4.8	6.1
25.5–34.0	10.2	10.1	9.6	8.6	6.3	5.4	11.3	13.5	13.2	5.0	4.4	2.9	5.0	5.3
34.0–42.5	10.5	11.3	10.0	11.4	7.3	6.2	14.2	15.2	13.4	6.0	5.0	3.0	4.8	5.3
42.5–51.0	9.3	11.5	10.5	11.5	10.3	6.5	16.4	17.1	15.4	4.5	5.0	3.1	4.8	4.7
51.0–59.5	10.1	10.3	11.0	10.7	12.1	6.9	17.2	16.0	11.8	5.6	5.1	3.1	5.2	4.7
59.5- 68.0	9.2	9.3	9.0	12.2	11.4	7.8	18.0	16.8	14.1	5.2	5.1	2.5	5.0	5.3
68.0–76.5	10.0	9.1	9.1	12.4	13.1	10.4	15.6	15.1	15.0	5.4	4.4	2.3	5.4	4.8
76.5 85.0	11.6	8.2	9.1	11.0	11.0	11.4	14.3	14.5	12.0	4.7	5.1	2.5	4.6	4.1
Checks	10.0	10.4	9.1	10.6	12.4	8.4	15.1	15.7	13.3	6.3	6.3	5.0	4.4	5.2

TABLE 6

RELATION BETWEEN CLAY CONTENT OF SOILS AND TOXICITY OF PHENYL MERCURI TRIETHANOL AMMONIUM LACTATE

Soil	Clay	No growth at:
	(per cent)	*(p.p.m.)*
Yolo fine sandy loam	14.94	320.0
Hanford fine sandy loam	16.44	490.0
Yolo clay loam	38.28	more than 680.0
Yolo adobe clay	50.8	220.0

TABLE 7

RELATION BETWEEN SOIL FERTILITY AND TOXICITY OF PHENYL MERCURI TRIETHANOL AMMONIUM LACTATE

Soil	Fresh weight of check	No growth at:
	(gm)	*(p.p.m.)*
Yolo adobe clay	6.9	220.0
Yolo fine sandy loam	9.0	340.0
Yolo clay loam	12.1	more than 680.0

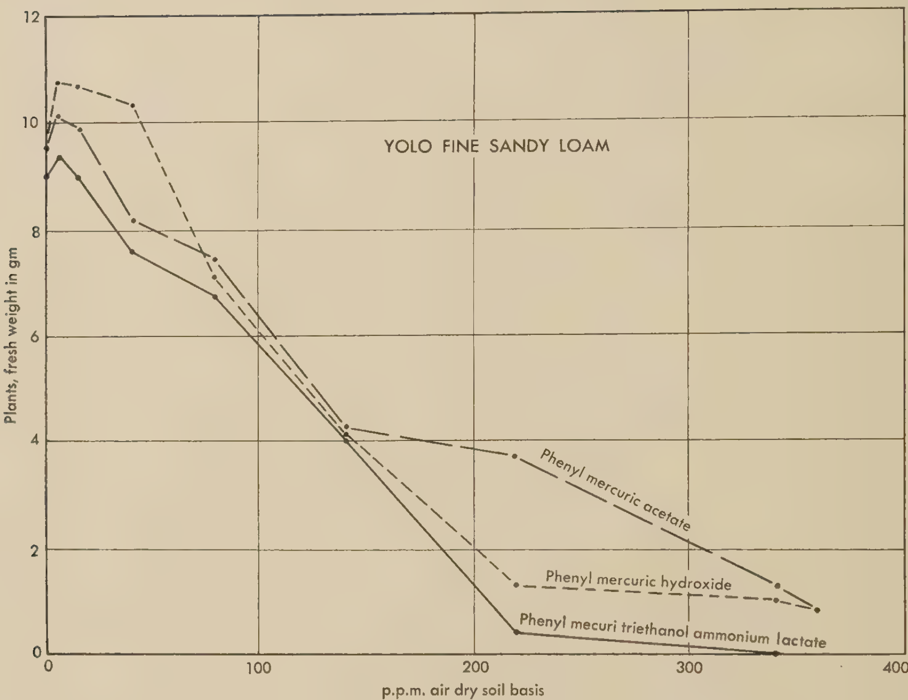

Fig. 1. Relation of crop yield to various concentrations of three phenyl mercuric compounds in Yolo fine sandy loam.

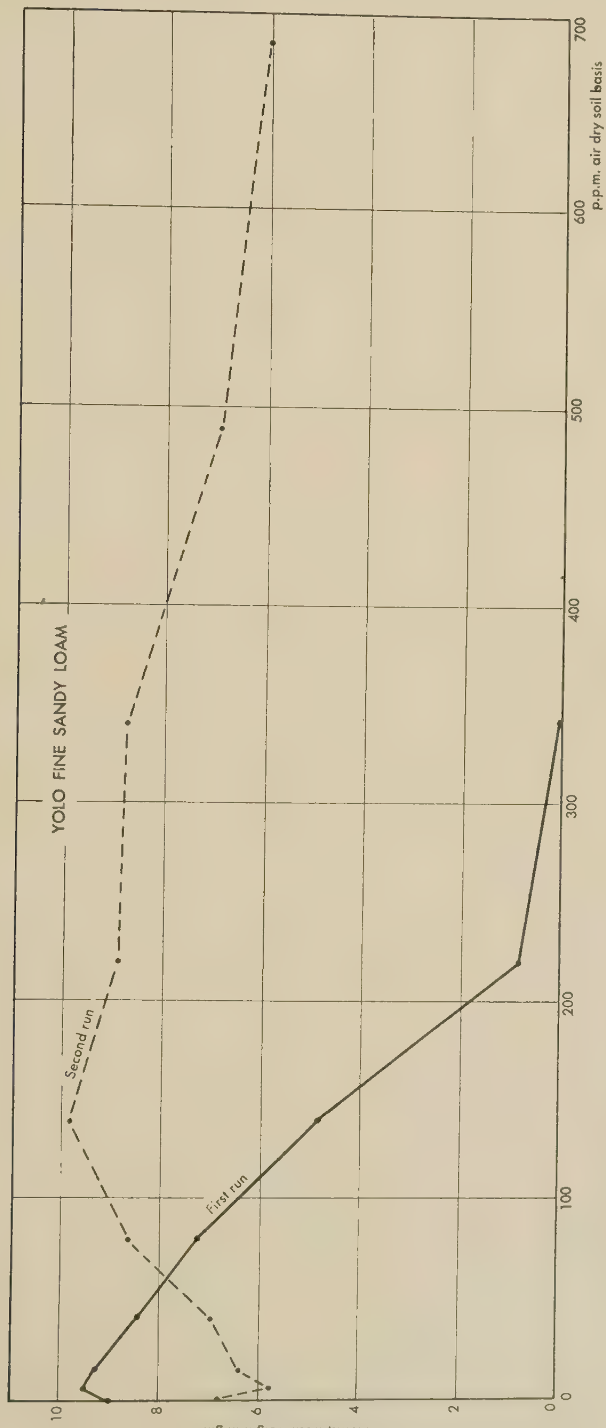

Fig. 2. Relation of crop yield to concentration of phenyl mercuri triethanol ammonium lactate in Yolo fine sandy loam.

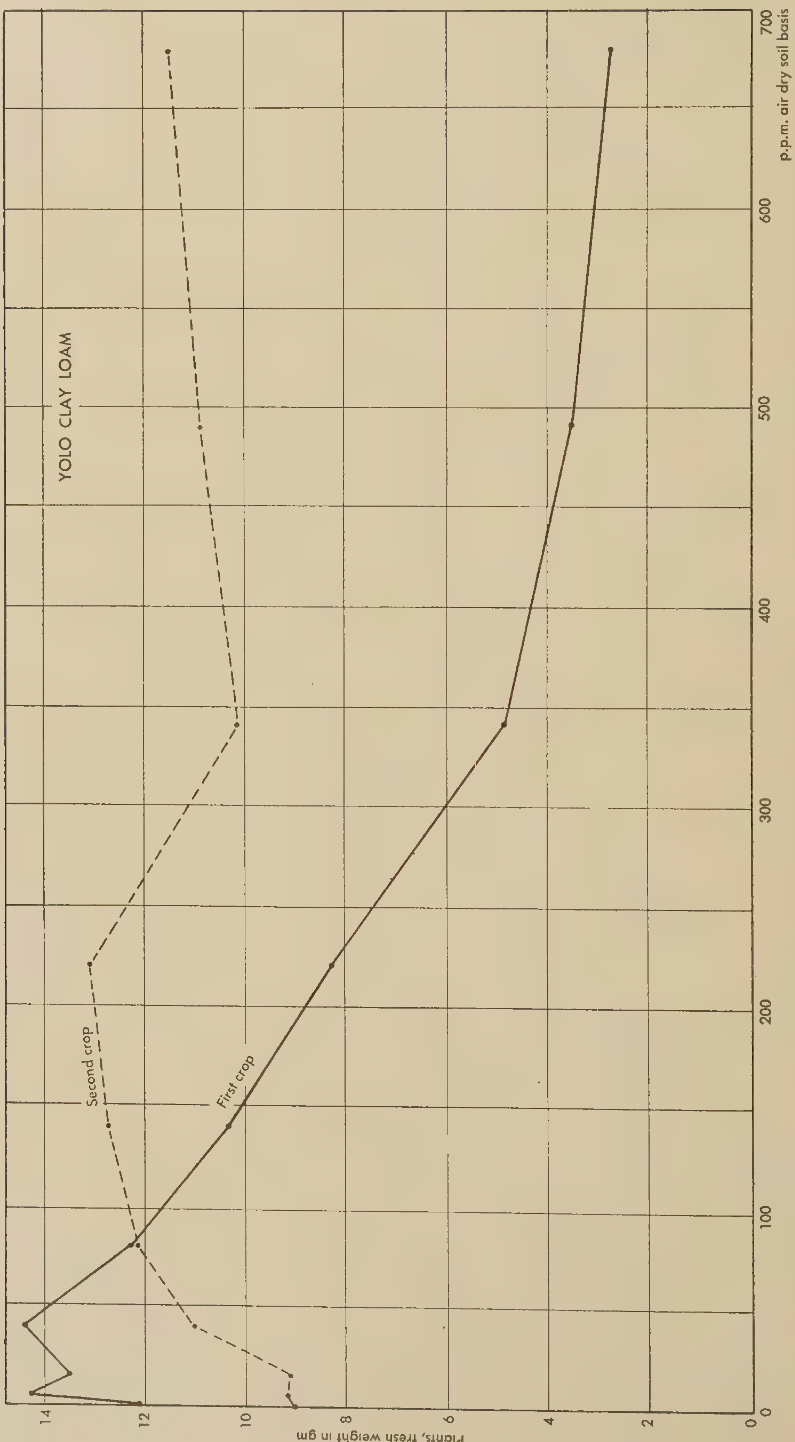

Fig. 3. Relation of crop yield to concentration of phenyl mercuri triethanol ammonium lactate in Yolo clay loam.

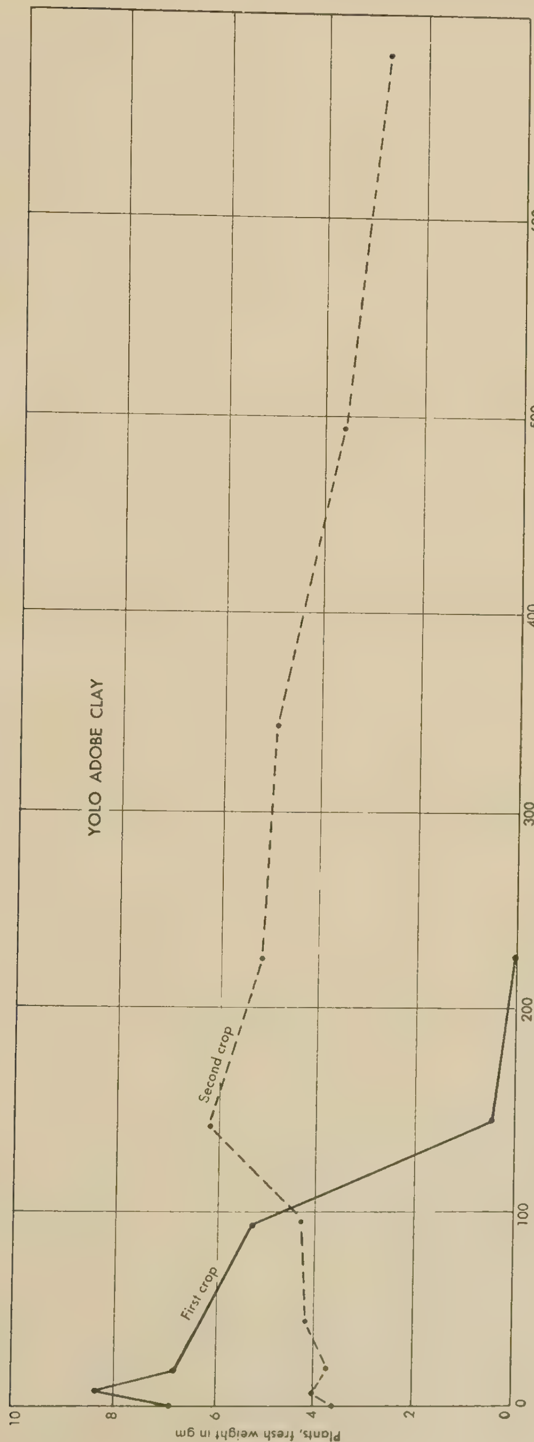

Fig. 4. Relation of crop yield to concentration of phenyl mercuri triethanol ammonium lactate in Yolo adobe clay.

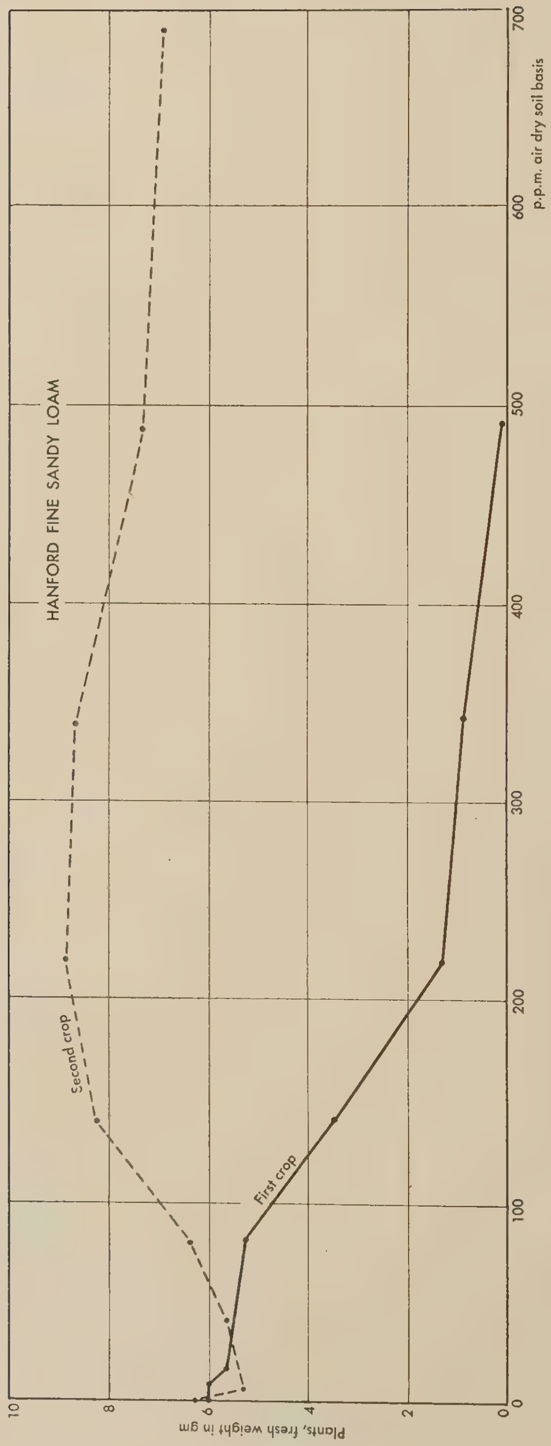

Fig. 5. Relation of crop yield to concentration of phenyl mercuri triethanol ammonium lactate in Hanford fine sandy loam.

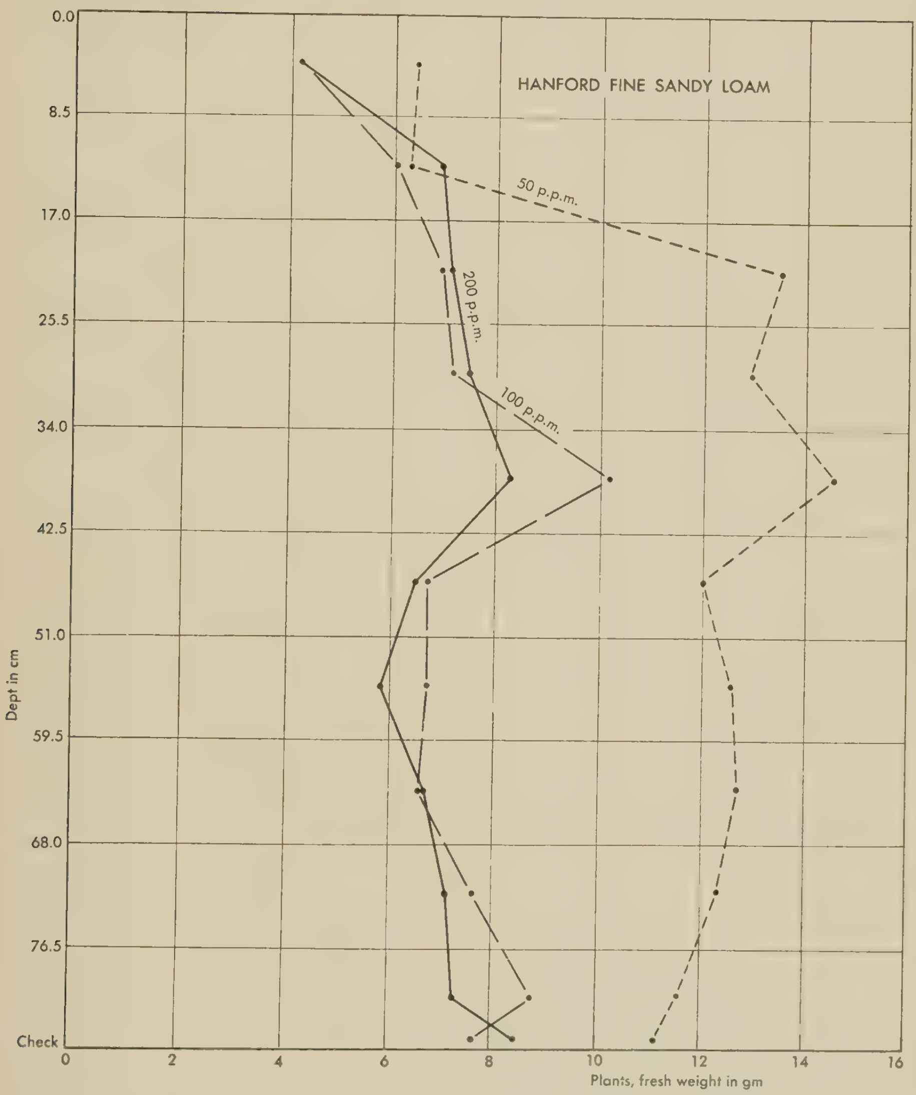

Fig. 6. Relation of crop yield to penetration of phenyl mercuric hydroxide in Hanford fine sandy loam.

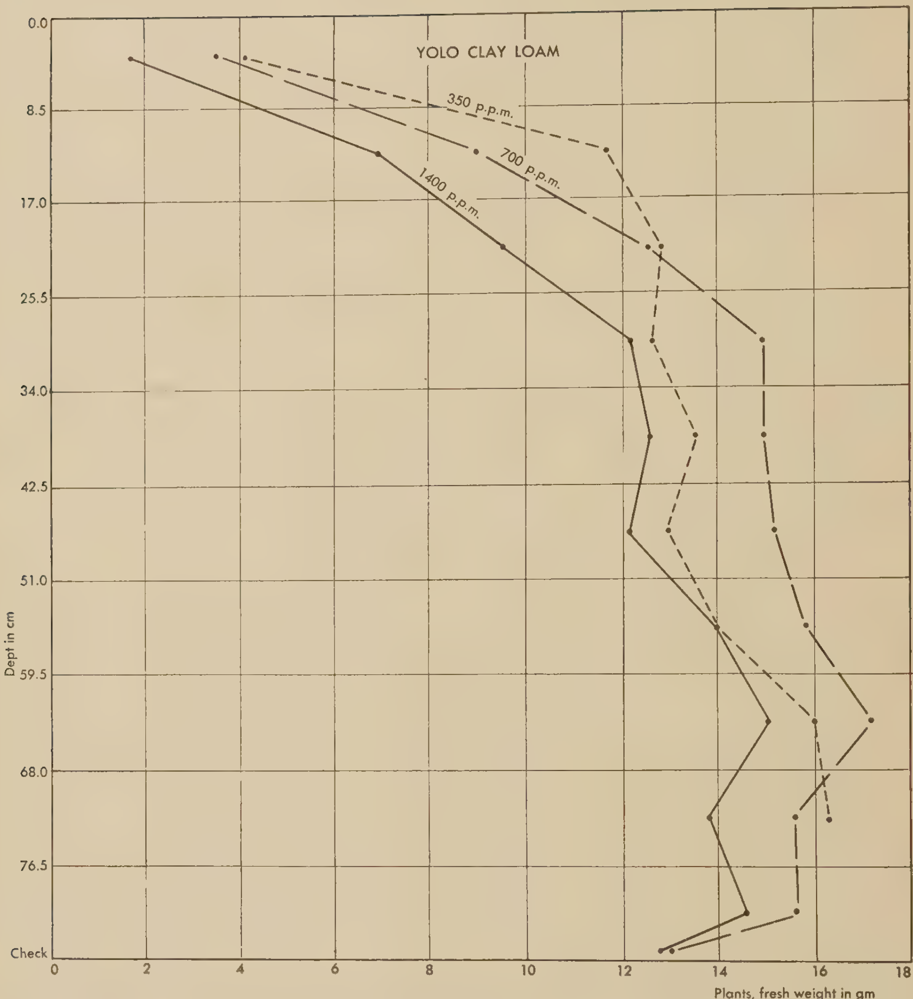

Fig. 7. Relation of crop yield to penetration of phenyl mercuric hydroxide in Yolo clay loam.

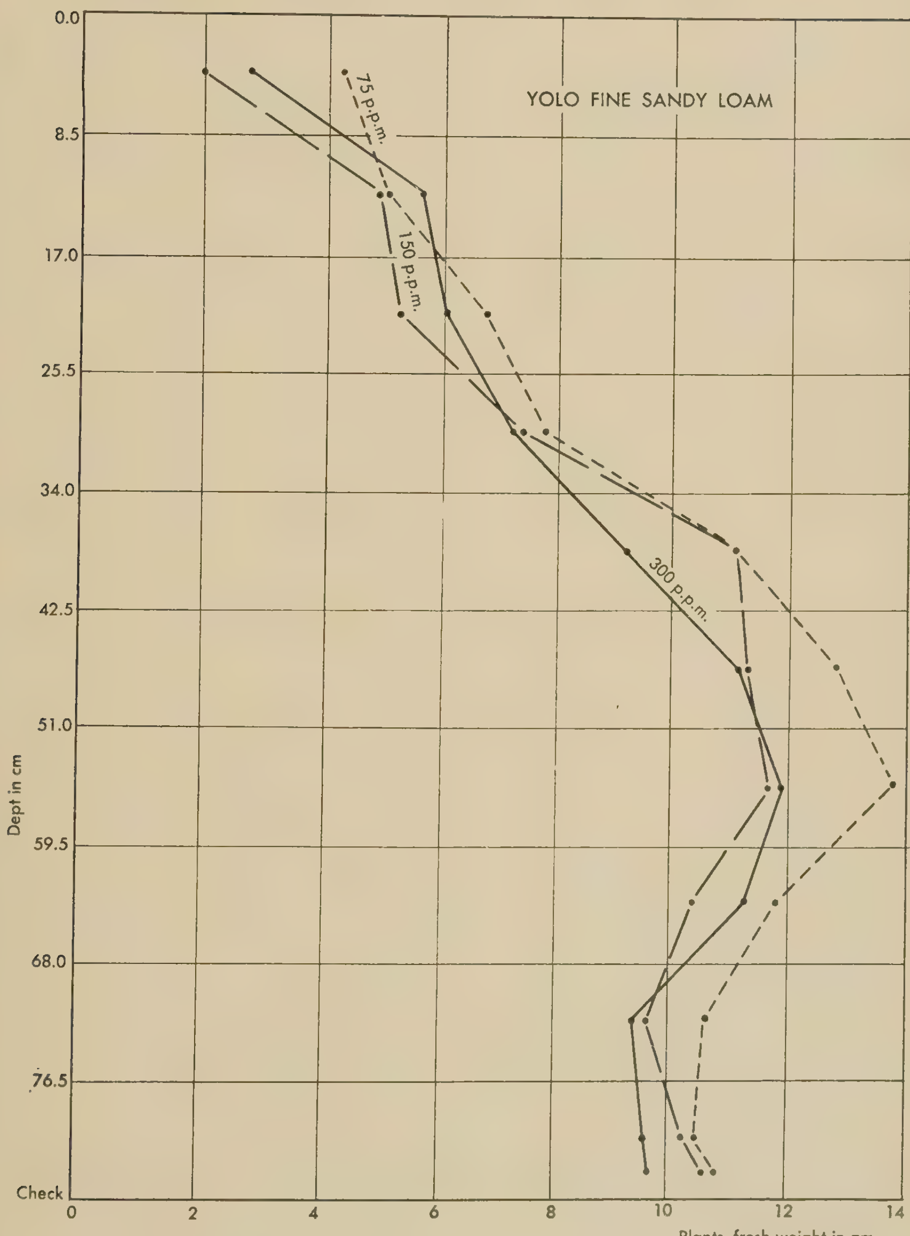

Fig. 8. Relation of crop yield to penetration of phenyl mercuric hydroxide in Yolo fine sandy loam.

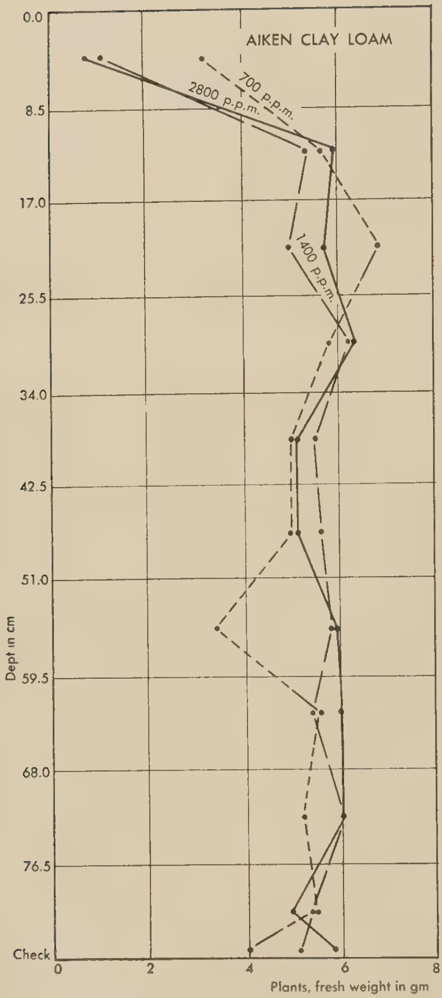

Fig. 9. Relation of crop yield to penetration of phenyl mercuric hydroxide in Aiken clay loam.

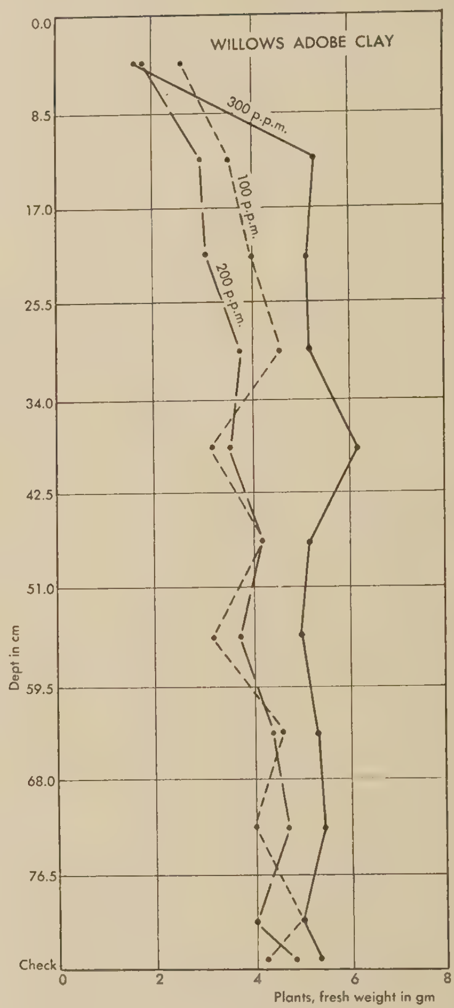

Fig. 10. Relation of crop yield to penetration of phenyl mercuric hydroxide in Willows adobe clay.

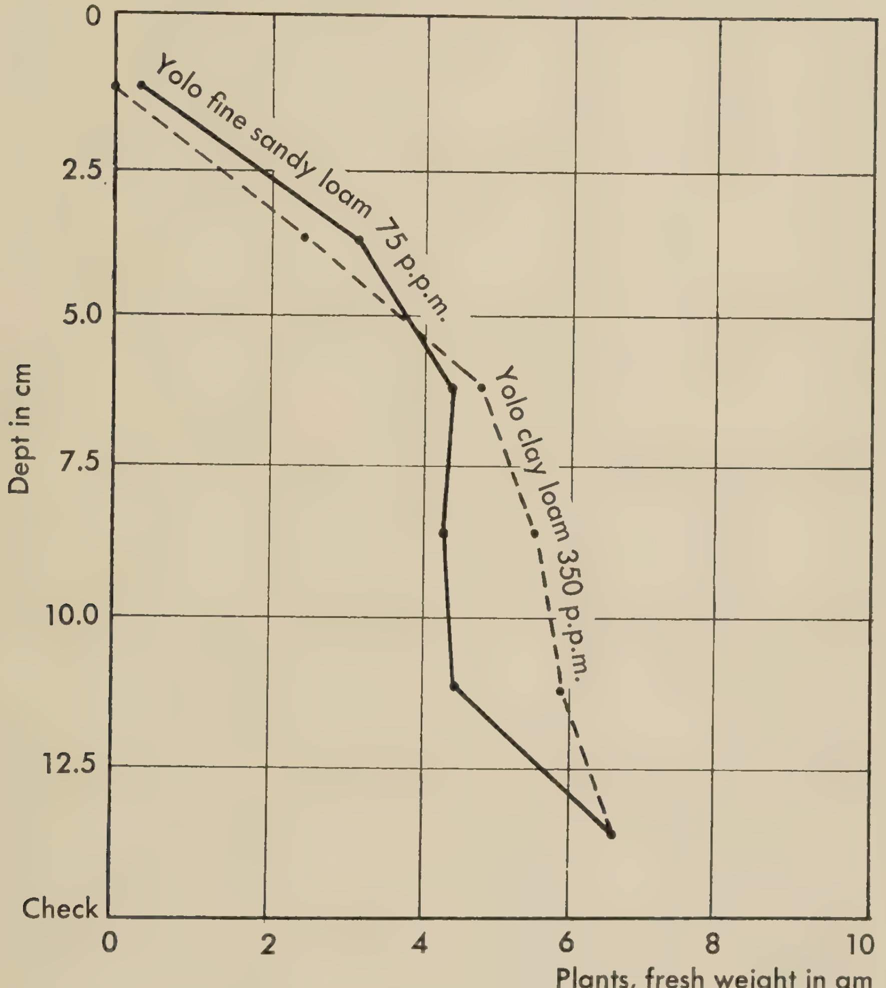

Fig. 11. Retention of phenyl mercuric acetate by two California soils.

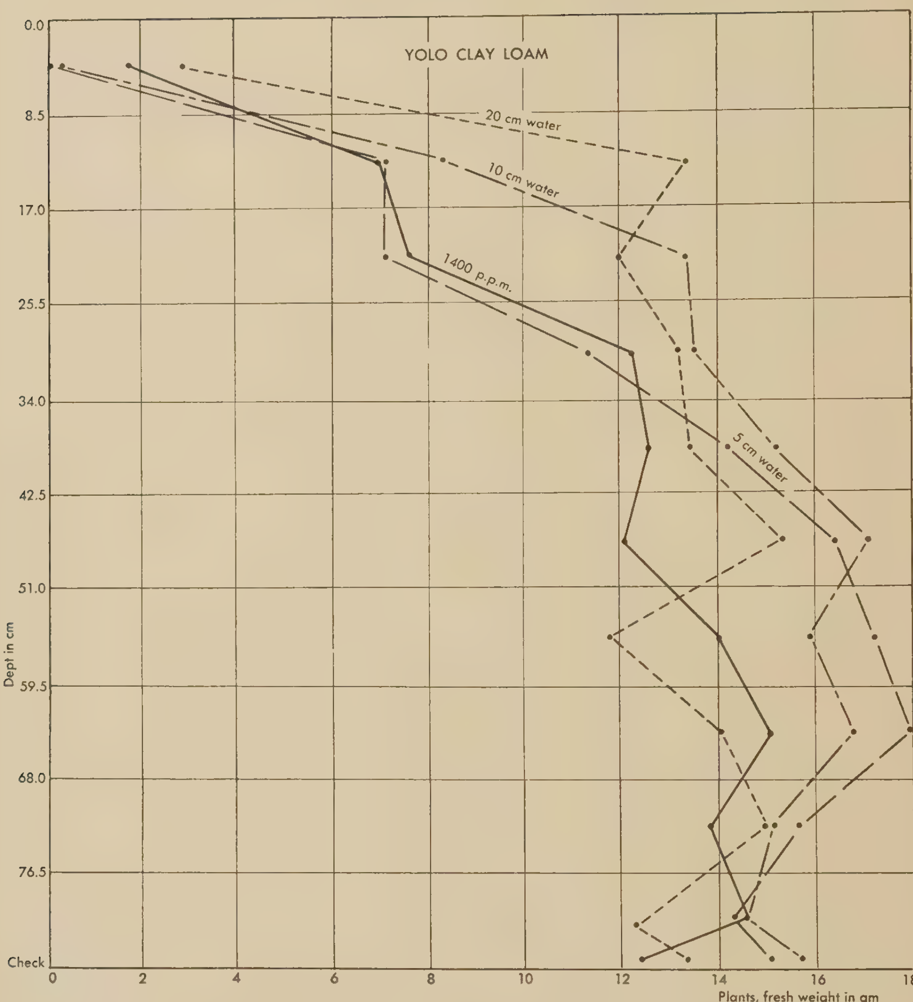

Fig. 12. Effects of leaching upon the location of phenyl mercuric hydroxide in Yolo clay loam.

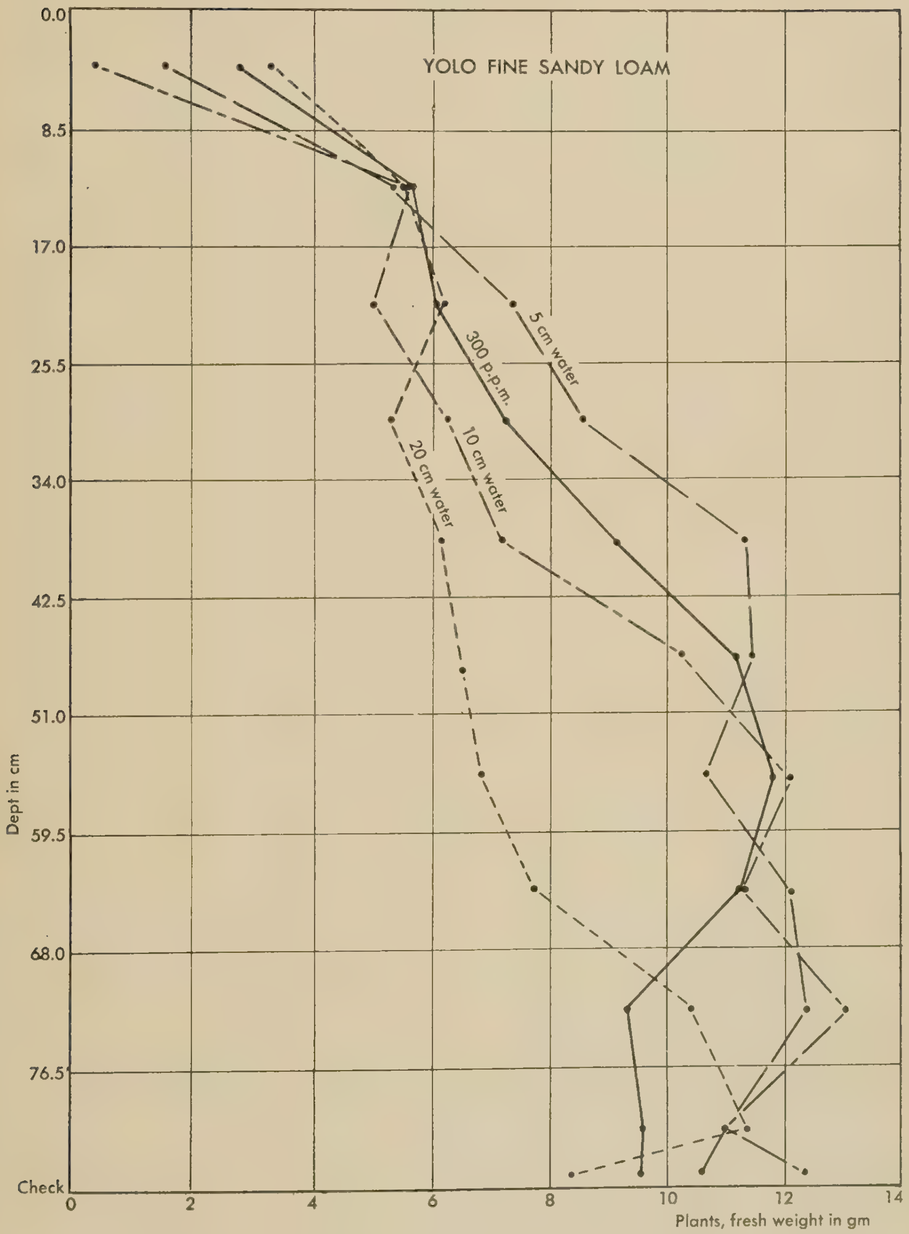

Fig. 13. Effects of leaching on the location of phenyl mercuric hydroxide in Yolo fine sandy loam.

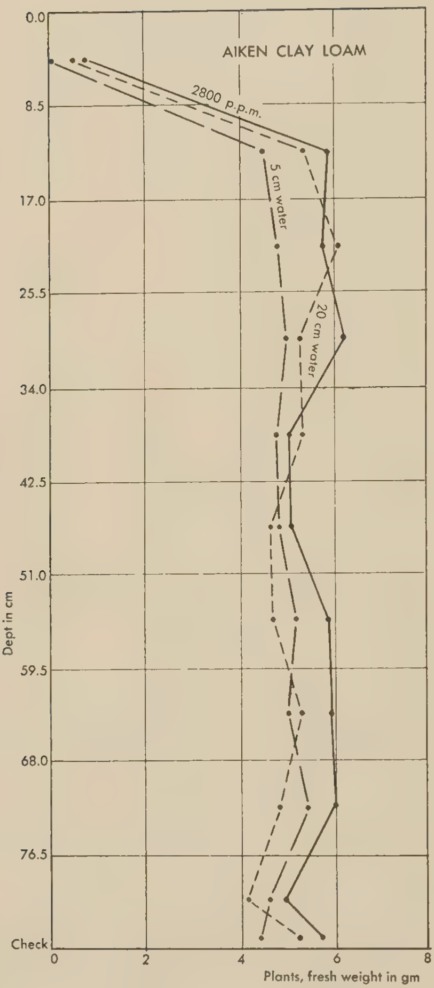

Fig. 14. Effects of leaching upon the location of phenyl mercuric hydroxide in Aiken clay loam.

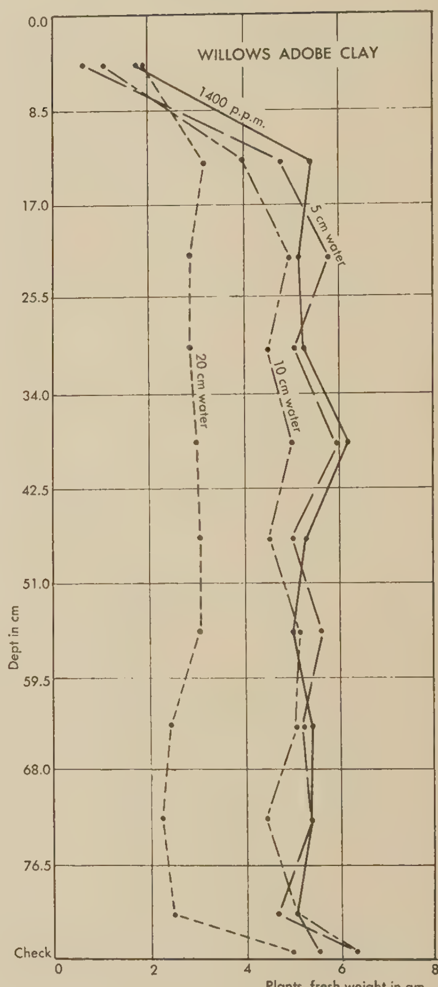

Fig. 15. Effects of leaching upon the location of phenyl mercuric hydroxide in Willows adobe clay.

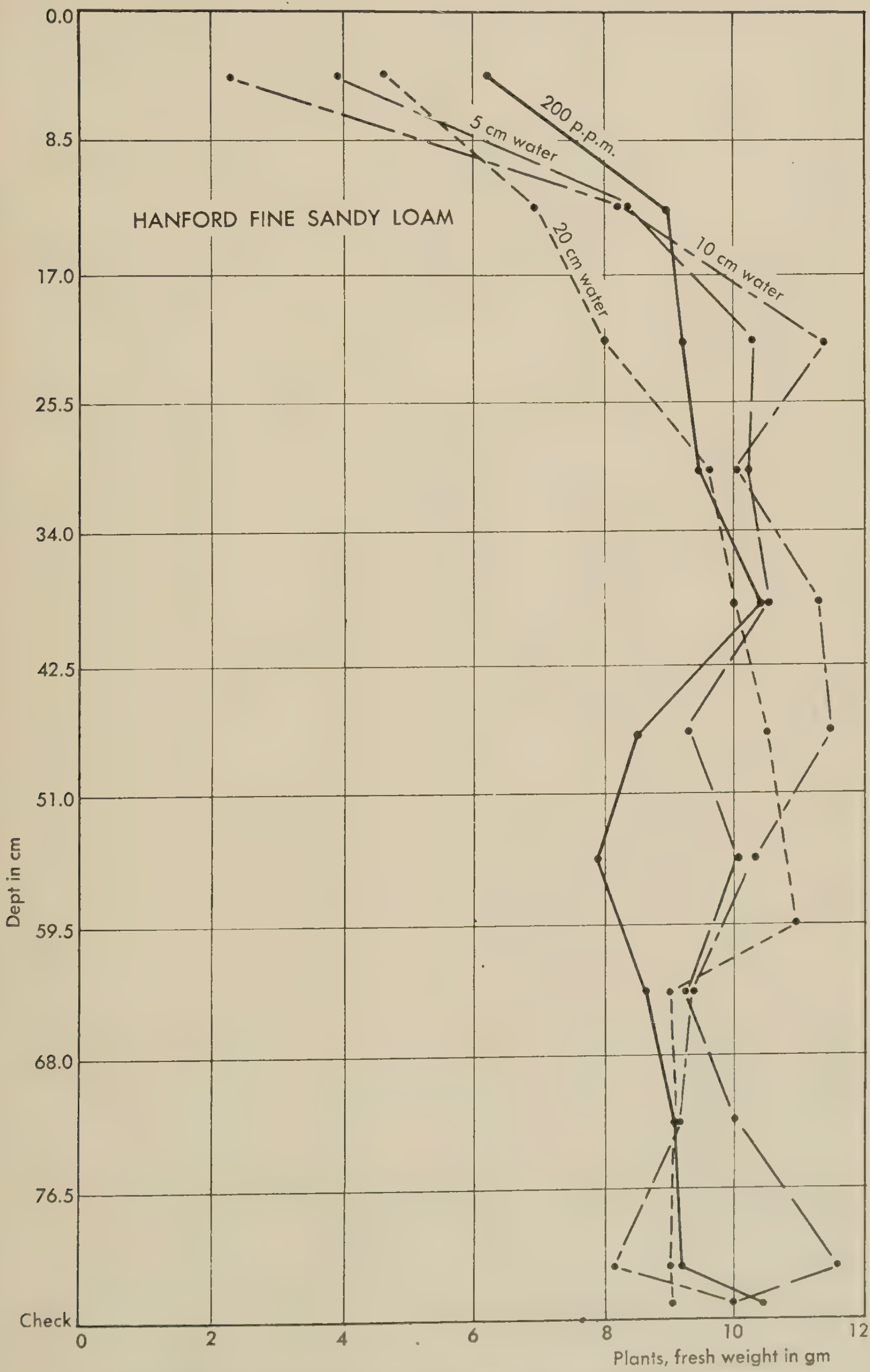

Fig. 16. Effects of leaching upon the location of phenyl mercuric hydroxide in Hanford fine sandy loam.

TOXICITY OF PENTACHLOROPHENOL AND ITS SODIUM SALT IN THREE YOLO SOILS[1]

W. A. HARVEY[2] and A. S. CRAFTS[3]

INTRODUCTION

IN 1940, HANCE[4] discovered a notable activation of herbicidal solution by using a water soluble chlorinated phenate. He found that the addition of ¼ to ⅕ of 1 per cent by weight of this activator and of an oxidizing substance to a herbicide solution reduced the concentration of weed killing chemical by from one half to one eighth that ordinarily used (depending on the toxic substance employed and the weeds) with equally satisfactory or even superior results. This activator has since been known as pentachlorophenol or PCP; it is available as the oil soluble parent phenol and as the water soluble sodium salt (Na PCP).

Crafts (1944) described studies where PCP was added to petroleum oils in order to fortify them so that the oil even when diluted or emulsified with water would remain effective. Good results were obtained by adding 0.5 per cent PCP to a 6 per cent diesel oil emulsion. Barley seems to be the only plant surviving two sprayings of this mixture. Hance (1948) mentions a mixture of sodium chlorate ($NaClO_3$) (20 pounds) and water soluble Na PCP (4 pounds) in 100 gallons of water as a good contact herbicide. Aldrich and Willard (1949) obtained good preëmergence weed control in corn by using 8 and 12 pounds Na PCP per acre. Heavy rain fell within 30 minutes after the application.

Many other workers (Barrons, 1948; Hance, 1948; Shafer, 1948; and Wilson and Hall, 1948) report encouraging results with PCP or with its Na salt, mostly as preëmergence treatments. This chemical is now being widely used, principally as a fortifying agent and in preëmergence applications. Sugar cane and pineapple are quite resistant to PCP; when the chemical is correctly applied, good results are obtained in preëmergence treatments.

According to Barrons (1948), selectivity is based on depth protection. The top growth pushing through the surface layer of soil containing the active chemical toxicant apparently does not absorb lethal amounts because the waxy stems or leaf surfaces do not permit the entry of such ionic materials as the phenolic salts. Roots that lack a waxy covering do absorb such salts, and germinating seeds are thus killed. These chemicals apparently have only an acute and local toxicity. The occasional injury resulting to top growth is, according to Barrons, noticeable only on cotyledons and primary leaves and does not affect subsequent growth.

The increasingly widespread use of PCP and its Na salt has created a need to determine their toxicity and their rate of breakdown in some California soils.

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[4] See "Literature Cited" for citations referred to in text by author and date.

MATERIALS AND METHODS

The soils used in the study were of the Yolo series, an agronomically important California soil of neutral reaction and of recent alluvial origin. Air dried and screened samples of fine sandy loam, clay loam, and adobe clay types were employed. The method followed in determining the initial residual toxicity of these herbicides was described in detail by Crafts (1944). PCP was added to the soil in dry, powdered form and thoroughly mixed on a revolving mixer. The soil was wetted to field capacity and seeded.

The Na salt (water soluble) was taken from a stock solution diluted to the desired volume to bring the soil to field capacity, added in three increments to obtain a more even distribution of the chemical, and then seeded.

The indicator plants used in both tests were Kanota oats. Thirty days after planting, plant heights and crop yields were recorded and the plant matter was returned to the cans. After 30 days of drying, the soil was pulverized and poured into the cans on top of the dried plant material; the cans were watered to bring the soil back to field capacity, reseeded, and run for 30 days as before. Five such runs were made and five replicates were used throughout. The concentrations used were: 0.0, 5.12, 10.24, 20.48, 41.0, 82.0, 164.0, 328.0, 656.0, and 1,213.0 p.p.m. pentachlorophenol on an air dry soil basis.

Figures 1 to 6 clearly show the slow decomposition of these compounds and the narrow range within which they remain quite effective in the soils. Little difference can be observed between the parent phenol and its sodium salt. Tables 1 and 2 indicate the actual experimental values obtained.

Examination of the results obtained, particularly the data for the second cropping, proves that whenever the chemical had decomposed, crop yields of treated soils were higher than the checks. The differences in yields between crops probably are due more to seasonal environmental conditions prevailing in the greenhouse than to any other cause.

DISCUSSION AND CONCLUSIONS

Several points of interest in the use of organic herbicides are shown by these experiments. It is important to note that there are no significant differences in toxicity between the straight pentachlorophenol and its sodium salt. Probably when the latter is added to the soil in solution the alkaline reaction is reduced by the soil buffer resulting in precipitation of PCP in a finely divided state. This is essentially the same condition that exists in the soils treated directly with PCP. Hence, from the standpoint of soil effects, it makes no difference whether the parent compound or its sodium salt is used; the end result is a soil toxicity related only to soil type and dosage. This may explain some of the disastrous results of using oil emulsions containing PCP as preëmergence sprays on sugar beets and other susceptible crops. Apparently the water solubility of the phenate is of little consequence once the chemical comes into intimate contact with the soil. It should be noted that in these tests both the PCP and the Na PCP were thoroughly mixed with the soil, not just sprayed on the surface where differential water solubility might affect movement into the soil.

It seems evident that under greenhouse conditions which could be described

as warm and moist, the PCP compounds tested did not break down appreciably in the soil over a period of 12 months. This is in decided contrast to other organic chemicals studied. Because PCP is a potent fungicide this failure of decomposition in warm moist soils may relate to an inhibition of microbiological activity in the treated soils.

This notable stability coupled with the fact that PCP compounds are not fixed on the clay fraction of the soil, thus moving freely with percolating water, indicate that residual toxicity may be a problem in regions of acid soils. Only leaching could be relied upon to rid the soil of this toxicant. Once the material is added and leached down into the soil, it retains its effectiveness for a long time regardless of soil type or fertility level. Because soils from the Yolo series only were tested, any generalizations concerning soils with different characteristics are hazardous.

However, previous experience with Yolo clay loam indicates that it might be expected to alter the toxicity of a chemical as much as almost any other California soil. Consequently, the build-up of residues of PCP in a great many soils might become a real problem.

As mentioned above, no fixation of PCP on the clay fraction could be detected in these experiments. Since such fixation might be expected to liberate minerals in an ionic form, thus making them available to plants, it is interesting to note that the second cropping data show marked increases in yields in almost all instances. Evidently some other mechanism is effective here. Possibly the same degree of toxicity that destroys microörganisms in the cultures showing continued inhibition of plant growth may, in the lower dosages, prevent microbial activity and, hence, bring about partial sterilization, a phenomenon that long has been known to stimulate growth of higher plants. Many soil microörganisms may be killed by these phenol compounds and their subsequent decomposition, or the absence of microbial activity may make available to the indicator plants the total supply of mineral elements in the soil. Such response would be particularly notable in the Yolo clay loam.

This difference in yields for particular values, which had caused severe growth inhibition in the first run, may, to a minor degree, be influenced by available minerals still not utilized. They therefore should be considered apart from general yield increases for different croppings that are probably due mostly to environmental conditions.

Preëmergence treatments with PCP compounds can be quite successful if sufficient moisture follows the application. For preëmergence treatments the Na PCP would appear to be the desirable form. Where weeds have already emerged but the crop has not, the use of PCP in oil as a contact spray has proved useful. Even with the parent phenol in oil, immediate rainfall may produce crop injury.

The results obtained in this experiment show that relatively large quantities of PCP are necessary to inhibit growth to any great extent. In this experiment the 164.0 and 328.0 p.p.m. used would be equivalent to more than 574 and 1,148 pounds of PCP per acre added in the field, and distributed in one acre foot of soil. Most workers report successful results with less than 40 pounds of PCP per acre, indicating that the chemical is active in a relatively shallow soil layer.

No reports of persistent residual toxicity in soils in which such quantities were used have been noted, and the amounts required to produce toxicity in these tests indicate little need to be fearful. In general, 164.0 p.p.m.—corresponding to 574 pounds per acre foot, at least 14 times that ordinarily used—produced no injury. If PCP toxicity should occur, leaching could be practiced or a different cropping system not requiring its use could be followed.

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TABLE 1

FRESH WEIGHTS OF KANOTA OAT PLANTS GROWN IN THREE CALIFORNIA (YOLO) SOILS CONTAINING INCREASING CONCENTRATIONS OF PENTACHLOROPHENOL
(Values are averages of five replicates)

PCP concentration in p.p.m. (air dry soil basis)	Soils		
	Yolo fine sandy loam	Yolo clay loam	Yolo adobe clay
	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)
	First cropping (November–December, 1948)		
0.00	6.5	8.3	4.9
5.12	6.6	10.1	4.2
10.24	6.5	9.6	4.4
20.48	6.8	9.4	5.2
41.00	5.6	9.0	4.7
82.00	5.2	7.7	4.0
164.00	3.8	6.9	3.0
328.00	1.8	3.8	0.9
656.00	0.6	1.6	0.4
1312.00	0.4	0.6	0.4
	Second cropping (February–March, 1949)		
0.00	10.1	15.3	6.9
5.12	9.1	17.0	5.6
10.24	9.6	16.7	6.1
20.48	9.6	17.0	7.2
41.00	9.9	17.4	8.1
82.00	10.3	17.5	9.3
164.00	9.5	16.5	8.0
328.00	1.2	2.4	0.6
656.00	0.5	0.6	0.4
1312.00	0.4	0.4	0.3
	Third cropping (May–June, 1949)		
0.00	6.6	11.0	4.9
5.12	6.3	13.3	4.3
10.24	6.3	11.8	4.0
20.48	6.4	12.0	4.7
41.00	6.1	12.2	4.4
82.00	7.0	12.8	5.1
164.00	8.0	12.5	7.5
328.00	0.4	1.7	0.6
656.00	0.3	0.4	0.3
1312.00	0.2	0.3	0.2
	Fourth cropping (September–October, 1949)		
0.00	3.5	5.1	3.2
5.12	3.5	6.1	3.7
10.24	3.4	6.6	3.5
20.48	3.3	6.7	3.0
41.00	3.2	7.2	3.2
82.00	3.3	6.4	3.3
164.00	2.9	6.0	2.9
328.00	0.5	1.7	0.8
656.00	0.2	0.3	0.4
1312.00	0.1	0.2	0.2
	Fifth cropping (December, 1949–January, 1950)		
0.00	4.2	5.9	3.7
5.12	4.1	6.8	3.6
10.24	4.4	6.6	4.2
20.48	4.4	6.1	3.5
41.00	4.0	6.1	3.6
82.00	4.2	6.2	3.8
164.00	4.1	6.1	4.1
328.00	0.7	4.1	0.4
656.00	0.2	0.4	0.3
1312.00	0.3	0.3	0.2

TABLE 2

FRESH WEIGHTS OF KANOTA OAT PLANTS GROWN IN THREE CALIFORNIA (YOLO) SOILS WITH VARIOUS CONCENTRATIONS OF SODIUM PENTACHLOROPHENATE
(Values are averages of five replicates)

PCP concentrations in p.p.m. (air dry soil basis)	Soils: Yolo fine sandy loam (*wt, gm*)	Soils: Yolo clay loam (*wt, gm*)	Soils: Yolo adobe clay (*wt, gm*)
	First cropping (November–December, 1948)		
0.00	7.4	6.5	6.9
5.12	7.5	6.1	5.8
10.24	7.2	7.1	5.4
20.48	6.7	6.9	5.5
41.00	6.4	6.5	4.7
82.00	5.8	5.8	2.4
164.00	1.1	3.1	0.8
328.00	0.5	3.0	0.3
656.00	0.2	1.6	0.2
1312.00	0.2	0.7	0.2
	Second cropping (February–March, 1949)		
0.00	9.0	8.0	6.2
5.12	9.5	7.3	5.9
10.24	10.4	8.0	6.3
20.48	10.1	8.4	7.0
41.00	10.1	9.1	8.6
82.00	7.8	15.1	4.2
164.00	15.8	4.4	0.8
328.00	0.6	1.4	0.4
656.00	0.4	0.5	0.6
1312.00	0.3	0.4	0.3
	Third cropping (May–June, 1949)		
0.00	7.0	7.7	5.1
5.12	7.4	7.7	5.1
10.24	8.0	7.9	5.4
20.48	7.0	7.1	6.3
41.00	7.1	7.1	7.3
82.00	8.4	8.0	8.4
164.00	2.3	10.0	1.8
328.00	0.3	8.4	0.3
656.00	0.3	0.3	0.3
1312.00	0.2	0.2	0.2
	Fourth cropping (September–October, 1949)		
0.00	3.4	5.0	3.4
5.12	3.4	5.5	3.5
10.24	3.8	5.2	3.8
20.48	3.6	5.2	3.4
41.00	3.7	5.0	3.5
82.00	3.4	4.5	3.6
164.00	4.7	4.4	1.9
328.00	0.6	1.3	0.5
656.00	0.3	0.3	0.4
1312.00	0.2	0.2	0.2
	Fifth cropping (December, 1949–January, 1950)		
0.00	4.1	6.0	3.8
5.12	4.4	6.7	4.0
10.24	4.4	6.0	4.0
20.48	4.3	5.9	3.9
41.00	4.5	5.9	4.4
82.00	4.4	5.8	4.5
164.00	7.5	5.2	6.2
328.00	1.1	2.8	0.5
656.00	0.3	0.4	0.3
1312.00	0.2	0.2	0.3

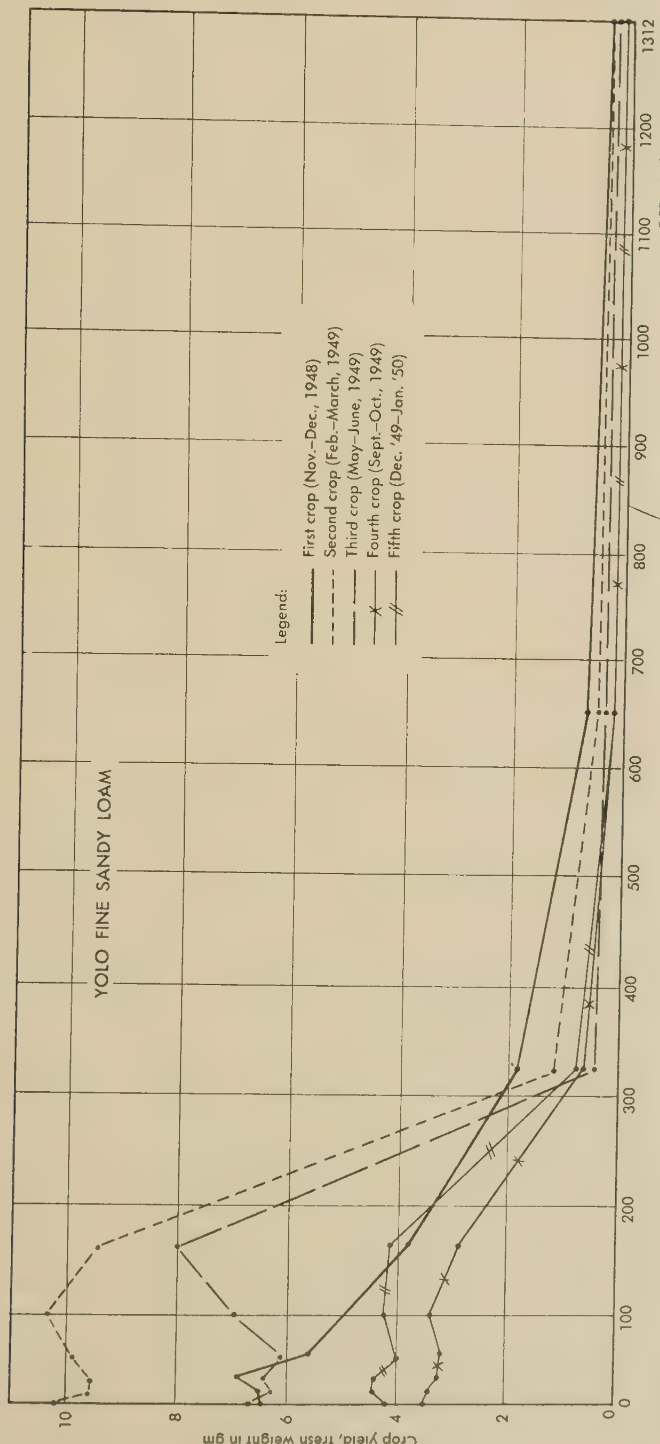

Fig. 1. Decomposition of pentachlorophenol in Yolo fine sandy loam, showing the narrow range within which it remains effective in soils from first through fifth crop.

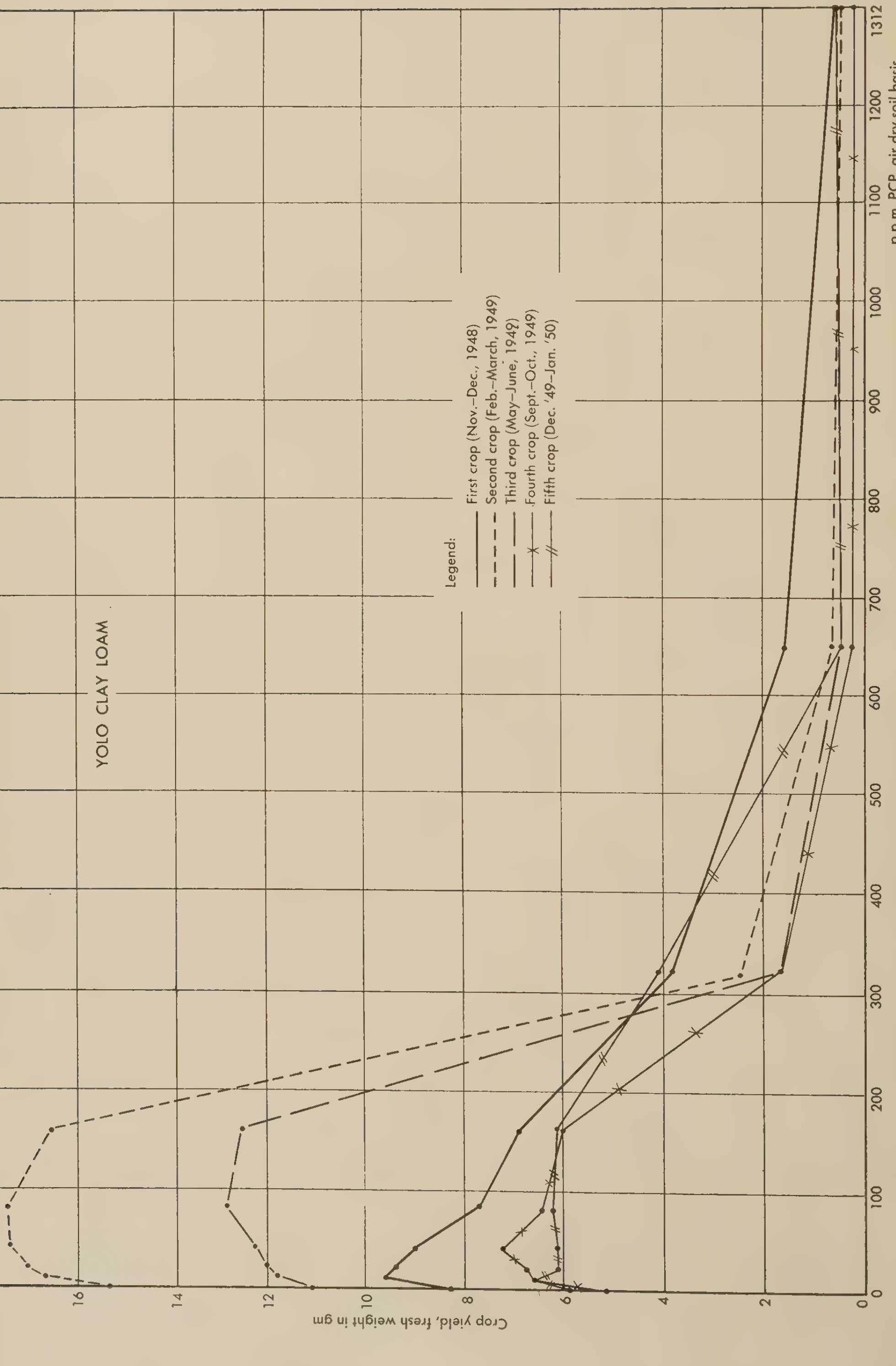

Fig. 2. Decomposition of pentachlorophenol in Yolo clay loam, showing the narrow range within which it remains effective in soils from first through fifth crop.

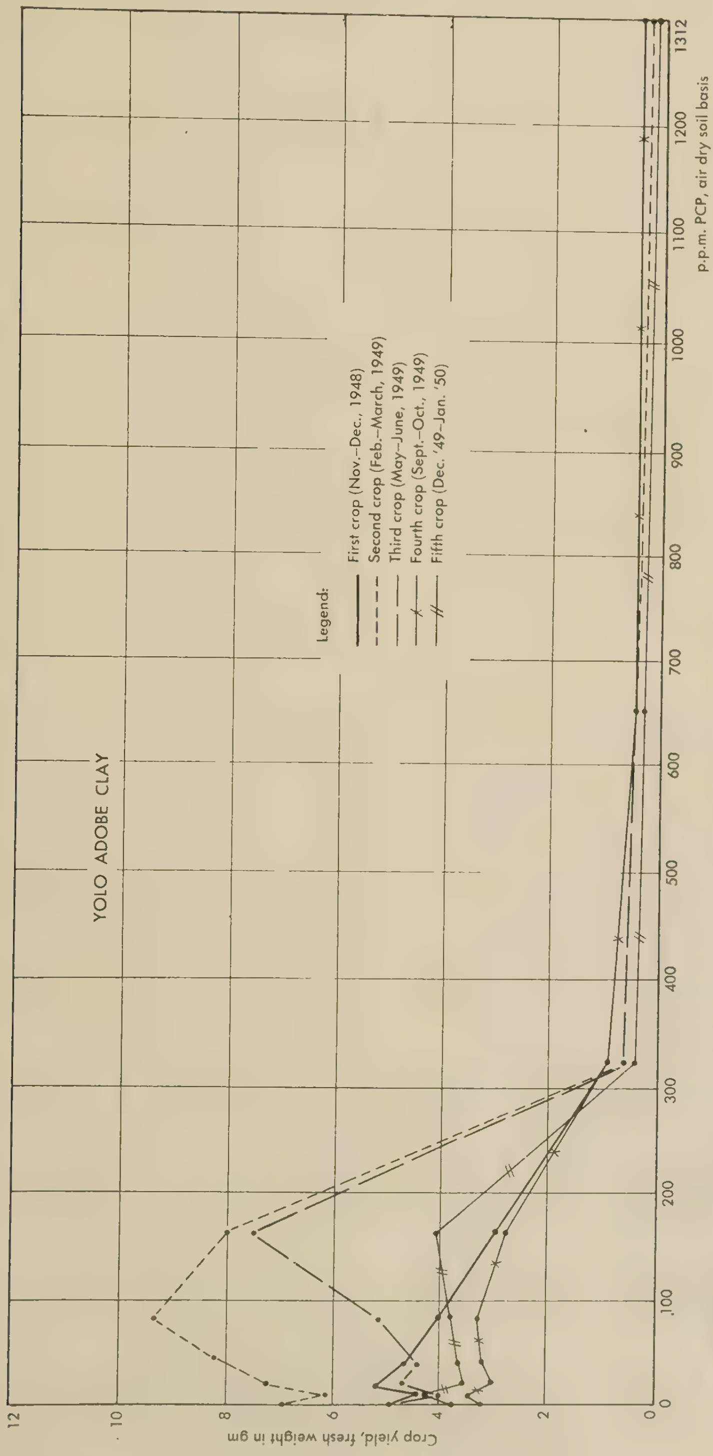

Fig. 3. Decomposition of pentachlorophenol in Yolo adobe clay showing the narrow range within which it remains effective in soils from first through fifth crop.

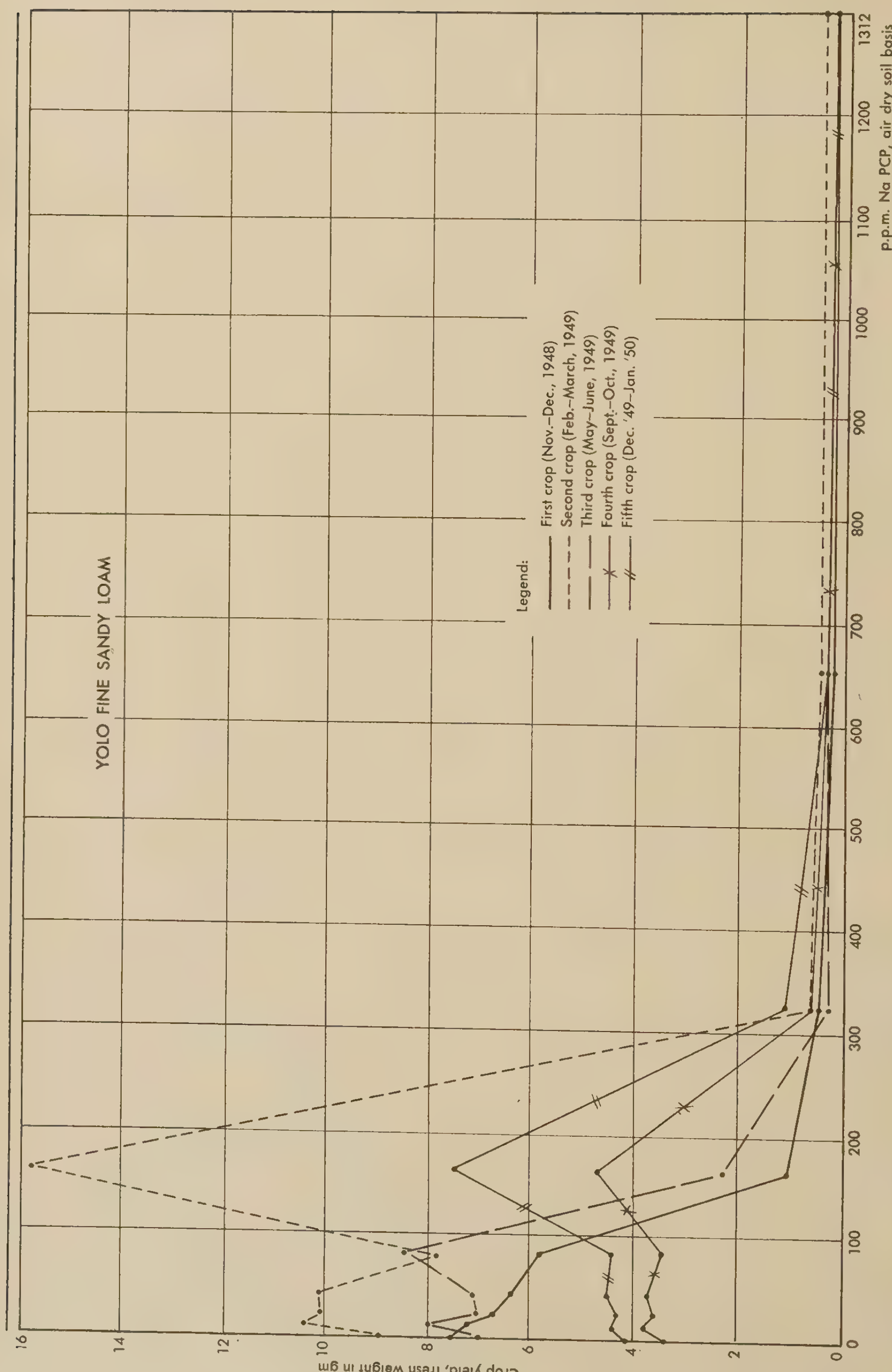

Fig. 4. Decomposition of sodium pentachlorophenate in Yolo fine sandy loam, showing range within which it remains effective in soils from first through fifth crop.

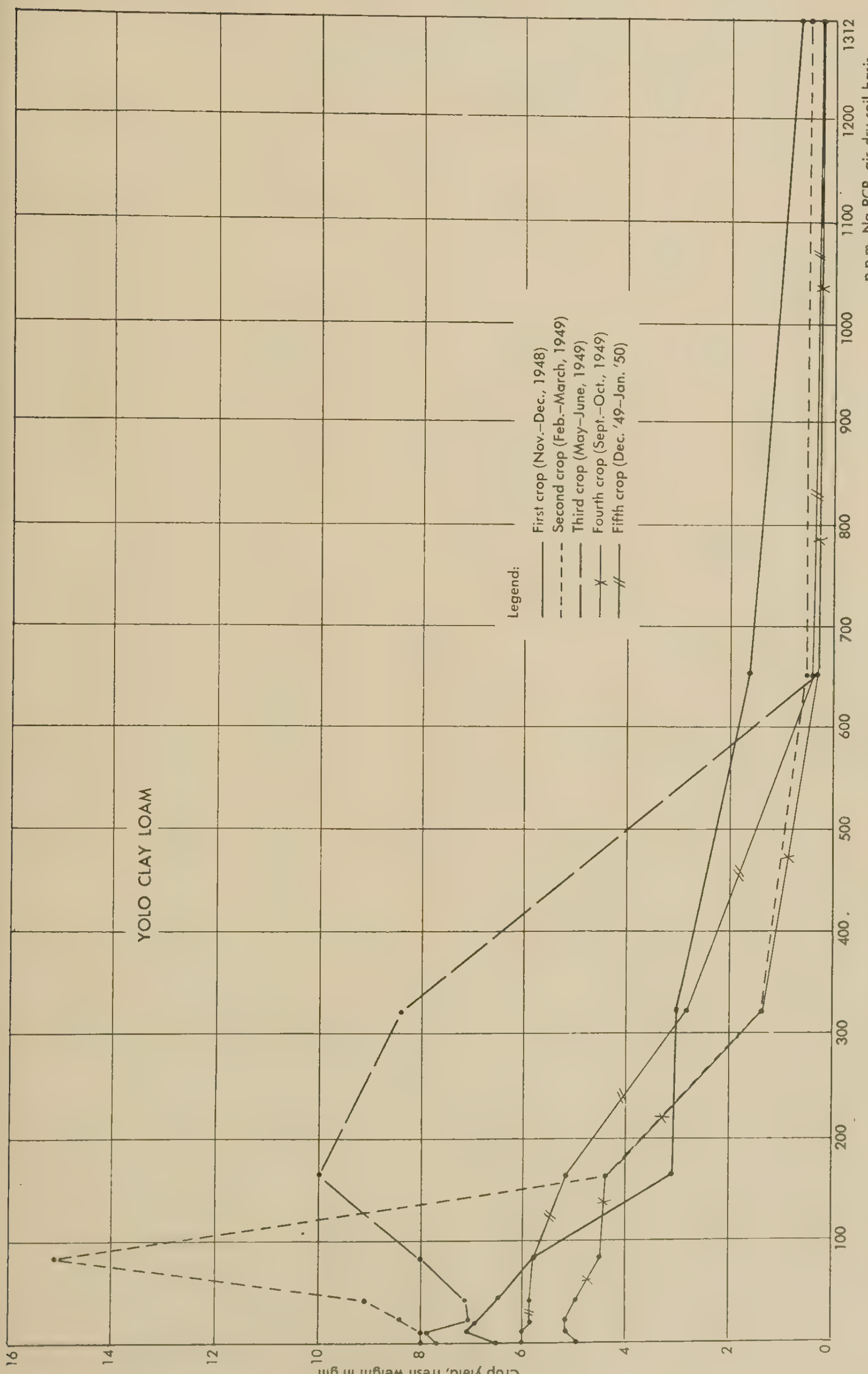

Fig. 5. Decomposition of sodium pentachlorophenate in Yolo clay loam, showing the narrow range within which it remains effective in soils from first through fifth crop.

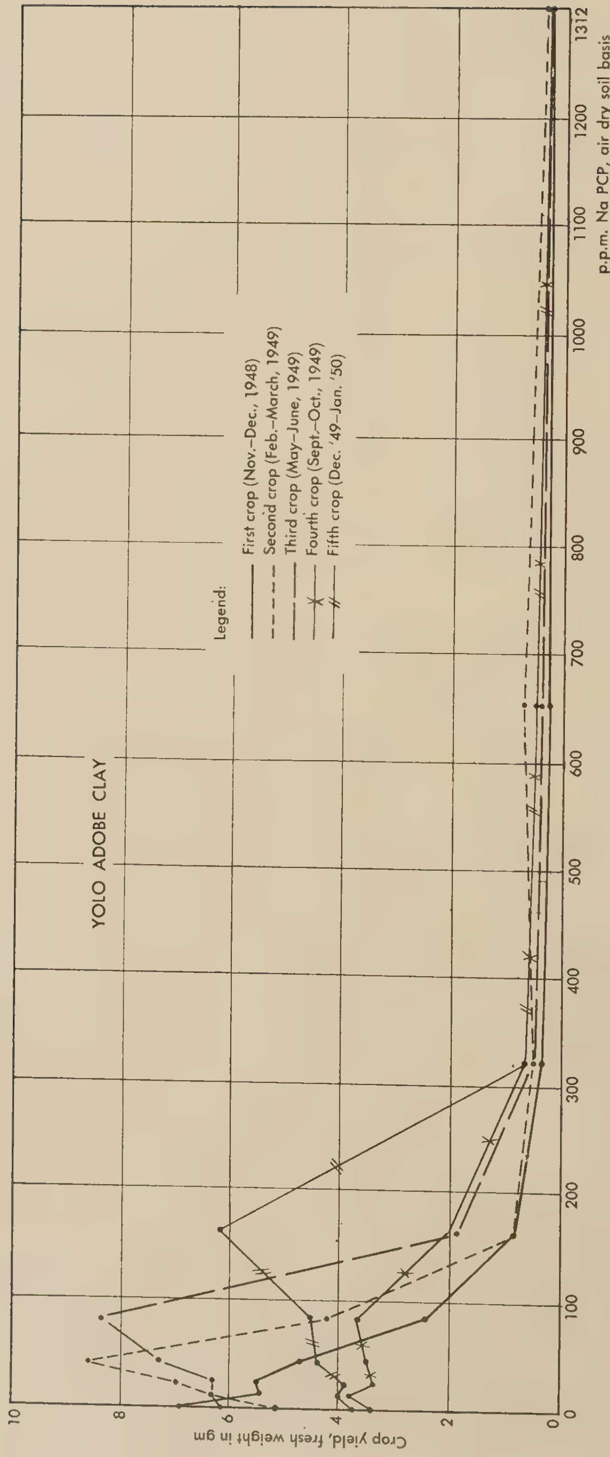

Fig. 6. Decomposition of sodium pentachlorophenate in Yolo adobe clay, showing the narrow range within which it remains effective in soils from first through fifth crop.

TOXICITY OF THREE 2,4-D FORMULATIONS IN CALIFORNIA SOILS[1]

W. A. HARVEY[2]

INTRODUCTION

One of the most widely publicized herbicides in recent years is 2,4-dichlorophenoxy acetic acid, commonly known as 2,4-D. In 1949 the acreage of crops successfully sprayed with this chemical ran into the millions. Because of its selectivity, it has been used primarily to control broad-leaved weeds in cereal crops. It has been used to a lesser degree to control perennial weeds, brush, and trees where no crop was involved. The chemical is usually applied in solution, emulsion, or suspension as a spray to the leafy vegetation of plants.

Blackman's (1945)[3] report that 2,4-D may act as a selective temporary soil sterilant suggested a new use for this chemical in the field of preëmergence weed control.

De Rose (1946) confirmed the toxicity of 2,4-D in soils. Crafts (1949), using three indicator plants, studied toxicity, rate of decomposition, and displacement in eight California soils, showing clearly the selectivity between monocots and dicots even in soil applications. The fact that 2,4-D acid is only slightly water soluble has led to the manufacture of various water and oil soluble formulations, the use of which is preferred or recommended in different cases. Since with 2,4-D it is possible to obtain herbicidal action by treatment of the soil as well as by foliage application, it was important to determine the toxicity and rate of inactivation of different formulations when in contact with the soil. It was also important to know whether the effect on subsequent crops depended upon formulation or was related to some particular soil characteristic.

MATERIALS AND METHODS

Air dried and screened samples of three California soils were used: Yolo fine sandy loam, Yolo adobe clay, and Hanford fine sandy loam. All three soils are of neutral reaction. Both series are of a recent alluvial nature; the Yolo is of sedimentary origin and the Hanford of an acid igneous parent material. Three indicator plants were used: Kanota oats, sunflowers, and vetch. Because of the greater resistance of monocots, the 2,4-D concentrations used for oats are ten times greater than those added to the dicot cultures. For the oats, the series was 0.0, 0.8, 1.6, 3.2, 6.4, 12.8, 25.6, 51.2, 102.4, and 204.8 p.p.m. 2,4-D acid equivalent, air dry soil basis.

Three formulations were studied: the water soluble sodium and triethylamine salts, and the oil soluble butyl ester.

The methods followed were described in detail by Crafts (1949). The necessary amounts of 2,4-D were measured from a stock solution or emulsion, diluted to a total volume calculated to bring the soil to field capacity, and

[1] Manuscript submitted for publication November 3, 1950.

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[3] See "Literature Cited" for citations referred to in text by author and date.

seeded. Thirty days after planting, the crops were cut off at ground level, and their fresh weights determined. After allowing the soil to dry out for a period of 30 days, it was pulverized, mixed, placed in the cans on top of the dried plant material, wetted to field capacity, and reseeded to determine the rate of decomposition of the chemical. Three such croppings were obtained in all cases.

RESULTS

Results are shown in figures 1 to 7 and tables 1 to 3. The toxicity and rate of decomposition of the three formulations, as can be seen in figures 1, 2, and 3, were quite similar in Yolo fine sandy loam when oats were used as the indicator plant. Figures 4 and 5 show yields of sunflowers and vetch in Yolo fine sandy loam to which increasing quantities of a butyl ester formulation of 2,4-D were added.

Figures 6 and 7 show crop yields of first and second croppings of oats and sunflowers obtained in the three soils to which the butyl ester formulation was added. A study of tables 1 to 3 will show that no important difference was obtained by the effects of the three different formulations considered.

Perhaps it is worth mentioning again that the 2,4-D was added on an acid equivalent basis, and not on formulation weight basis.

DISCUSSION AND CONCLUSIONS

The actual toxicity and subsequent inactivation of 2,4-D acid in California soils were previously studied and reported in detail by Crafts (1949). In brief, he concluded that toxicity was sufficient to reduce growth during the first cropping in the eight soils he considered (three of which are reported in these studies), but little toxicity remained by the second cropping, and a certain stimulation was noted in the third cropping. Breakdown was apparently slower in neutral and alkaline soils than in acid ones. Moderate fixation on clay was noted, and leaching experiments using 320 surface centimeters of water did not completely rid two soils of 2,4-D.

In that same report, Crafts mentioned the anomalous behavior of Yolo adobe clay, which fixed less 2,4-D than lighter soil types. From its clay content this soil might be expected to have a high fixing power. The experiments reported here tend to confirm those reported by Crafts. Again, here, the behavior of Yolo adobe clay was anomalous; the slight difference in clay content (14.94 per cent for Yolo fine sandy loam, and 16.44 per cent for Hanford fine sandy loam) between the other two soils is not sufficient to explain the evident difference in 2,4-D toxicity. However, if the two Yolo soils are considered separately, a correlation could be found with clay content, as shown by table 4.

In addition to the fact that the initial toxicity was the same for the three formulations considered, their subsequent inactivation was also quite similar. The largest dosages—204.8 p.p.m. for the oats and 20.48 p.p.m. for the sunflowers and vetch—caused appreciable growth reduction during the second and third croppings only to the vetch.

As was pointed out by Crafts (1948) breakdown of 2,4-D is accompanied by a certain increase in growth of oats and sunflowers. However, no appreci-

able increase in yield was noted when vetch was used as the indicator plant. Such increases in growth were highest when the sodium salt was applied. It seems possible that a base exchange mechanism may be involved. Because of the minute quantities of chemicals added, it hardly seems possible that a direct nutrition of the plant is concerned. If direct nutrition did occur, the triethylamine by releasing nitrogen should give the highest yields, which it does not.

If the crop yields of the checks are taken as indices of soil fertility, no actual relation could be found between this soil characteristic and the 2,4-D toxicity or its inactivation.

On the basis of studies with these three soils, it is difficult to generalize upon the differences in behavior of various 2,4-D formulations in soils, but it is possible to state that under greenhouse conditions their action through the soil is not different.

Warren and Hernandez (1948), working sodium and amine salts and isopropyl ester formulations into the soil just before planting onions, obtained results that showed no significant difference from the effects of the formulation, except that perhaps isopropyl ester gave a little greater kill.

It should be emphasized that the results obtained in these experiments are from each of the three formulations thoroughly mixed with a given quantity of soil. Under these conditions it appears to make no difference which formulation is used. Field observations with the different materials applied to the soil surface have shown that the water soluble forms are more effective than the esters insofar as immediate effect on prevention of germination is concerned.

The experiments reported here lead to the conclusion that all three forms act alike when mixed with the soil. This would appear contrary to the theory (Crafts, 1948) that the nonpolar ester should enter through the roots more slowly or to a lesser extent than the more polar sodium or amine salts. However, it might be inferred that in the soil all three forms act alike because they all revert to the parent acid through buffering action and hydrolysis. This would be in agreement with the theory since the acid is sufficiently polar to be effective through root absorption. The field observations on the lower effectiveness of the ester applied to the surfaces of the soil would also fit this scheme since it is possible that decomposition of the acid proceeds at about the same rate as its formation from the ester by hydrolysis. If the effective form of 2,4-D in the soil is that of the acid, then for soil application the use of finely ground acid rather than other formulations should be the most economical practice.

ACKNOWLEDGMENT

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TABLE 1

FRESH WEIGHTS OF KANOTA OATS GROWN IN THREE CALIFORNIA SOILS CONTAINING VARIOUS CONCENTRATIONS OF THREE DIFFERENT FORMULATIONS OF 2,4-D

Concentration 2,4-D acid equivalent in p.p.m. (air dry soil basis)	Soils								
	Yolo fine sandy loam			Hanford fine sandy loam			Yolo adobe clay		
	Formulation			Formulation			Formulation		
	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt
	First cropping								
	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)
0.0	2.9	2.8	3.1	5.0	5.4	5.6	5.4	4.3	5.7
0.8	2.4	1.8	1.7	5.0	3.4	5.0	4.9	3.5	4.9
1.6	0.6	1.1	1.2	3.6	3.3	4.3	4.3	3.3	3.3
3.2	0.4	0.5	0.7	3.4	2.1	2.9	2.7	2.5	2.5
6.4	0.3	0.2	0.3	0.8	1.0	1.3	1.2	1.3	1.2
12.8	0.1	0.2	0.2	0.3	0.4	0.4	0.2	0.2	0.3
25.6	0.1	0.2	0.2	0.2	0.3	0.2	0.2	0.1	0.2
51.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.2
102.4	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.0	0.1
204.8	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0
	Second cropping								
0.0	5.7	3.3	3.3	7.8	6.4	6.2	4.6	3.7	4.5
0.8	3.4	4.1	3.8	7.1	7.7	7.5	5.1	5.1	4.9
1.6	3.7	3.5	3.6	7.5	8.6	6.5	5.0	5.5	4.5
3.2	4.7	3.2	3.9	9.1	7.4	8.1	6.7	6.2	5.3
6.4	2.6	3.2	4.1	9.4	7.7	9.1	7.2	6.9	5.8
12.8	1.8	4.0	3.8	6.7	7.2	9.4	6.1	7.0	6.4
25.6	2.4	4.3	2.7	7.8	6.6	8.0	6.9	6.4	6.0
51.2	2.3	4.0	1.6	6.6	5.5	8.8	6.5	6.5	7.3
102.4	2.0	3.5	3.3	5.8	5.1	...	5.4	3.1	6.3
204.8	1.3	0.5	3.2	6.6	6.5	9.0	3.3	2.1	5.7
	Third cropping								
0.0	1.5	2.2	1.9	6.0	4.4	4.4	3.1	2.7	2.7
0.8	3.2	2.5	2.2	5.5	5.4	4.4	3.4	2.7	3.1
1.6	3.3	2.5	2.6	6.3	6.5	6.1	3.4	3.0	2.7
3.2	4.3	2.3	2.4	6.4	6.0	4.8	4.4	2.8	4.1
6.4	3.8	3.4	3.1	7.9	5.5	6.7	4.3	3.3	2.9
12.8	4.4	3.0	2.9	7.0	5.9	6.4	5.2	3.7	3.3
25.6	4.2	5.1	3.9	7.0	5.6	7.5	5.3	4.5	3.6
51.2	4.5	3.5	4.0	7.4	6.5	7.8	4.3	2.8	3.2
102.4	3.9	3.4	3.3	7.1	6.1	4.1	4.6	6.0	4.4
204.8	3.9	4.5	3.3	5.9	6.9	7.1	6.0	6.3	5.0

TABLE 2

FRESH WEIGHTS OF SUNFLOWERS GROWN IN THREE CALIFORNIA SOILS CONTAINING VARIOUS CONCENTRATIONS OF THREE DIFFERENT FORMULATIONS OF 2,4-D

Concentration 2,4-D acid equivalent in p.p.m. (air dry soil basis)	Soils								
	Yolo fine sandy loam			Hanford fine sandy loam			Yolo adobe clay		
	Formulation			Formulation			Formulation		
	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt
	First cropping								
	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)	(*wt, gm*)
0.0	5.1	2.7	2.4	10.8	10.8	13.1	8.6	8.5	9.1
0.08	1.4	1.0	4.7	11.8	10.4	11.5	8.1	8.4	9.7
0.16	0.4	1.8	1.5	9.2	11.2	10.7	8.0	8.4	7.9
0.32	0.4	1.0	2.4	10.7	11.6	10.9	7.0	7.6	6.9
0.64	0.0	0.4	0.0	8.8	10.4	9.4	5.4	4.9	5.7
1.28	0.0	0.0	0.0	9.2	4.6	7.3	1.0	3.0	0.9
2.56	0.0	0.0	0.0	5.4	1.8	2.0	0.0	0.0	0.2
5.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Second cropping								
0.0	9.7	11.0	10.0	13.5	10.2	11.4	9.3	11.6	9.4
0.08	...	14.0	11.7	15.8	13.3	13.6	9.1	11.2	10.7
0.16	11.5	13.1	8.3	12.0	15.2	16.0	9.3	11.6	10.5
0.32	10.6	13.9	8.4	14.1	15.7	14.6	9.4	10.1	12.0
0.64	10.5	12.4	9.7	17.9	13.3	14.6	12.3	11.0	10.4
1.28	11.5	11.4	8.8	17.0	14.0	13.8	13.0	12.1	9.9
2.56	8.8	10.6	9.8	15.8	11.2	15.0	11.2	15.0	14.2
5.12	5.2	9.5	7.6	17.0	15.3	19.7	5.1	13.4	12.1
10.24	4.9	5.2	7.8	18.0	10.2	15.1	7.8	13.7	9.7
20.48	5.4	6.3	4.9	9.0	13.6	14.8	3.4	10.5	10.0
	Third cropping								
0.0	7.9	9.6	5.5	10.6	11.3	13.7	8.1	7.8	8.0
0.08	...	7.7	7.8	9.2	10.7	11.0	8.7	9.3	8.5
0.16	8.2	6.3	7.9	11.5	10.3	13.4	11.2	7.2	9.0
0.32	7.8	7.9	7.9	11.7	14.1	11.1	8.4	8.4	8.1
0.64	7.9	7.2	7.4	13.5	12.9	13.1	9.4	9.8	8.8
1.28	7.8	6.1	7.6	11.3	12.5	12.2	10.0	10.5	9.9
2.56	8.4	8.6	7.6	13.0	11.6	12.3	9.3	11.5	8.4
5.12	8.9	8.6	7.8	11.4	11.6	11.2	9.5	8.3	9.6
10.24	8.5	8.0	10.8	13.7	11.6	12.9	11.1	9.9	9.4
20.48	10.7	9.6	9.9	11.7	11.1	11.6	12.5	11.8	9.5

TABLE 3

FRESH WEIGHTS OF VETCH GROWN IN THREE CALIFORNIA SOILS CONTAINING VARIOUS CONCENTRATIONS OF THREE DIFFERENT FORMULATIONS OF 2,4-D

Concentration 2,4-D acid equivalent in p.p.m. (air dry soil basis)	Soils								
	Yolo fine sandy loam			Hanford fine sandy loam			Yolo adobe clay		
	Formulation			Formulation			Formulation		
	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt	B.E.	T.E.A.	Na salt
	First cropping								
	(wt, gm)	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*	*(wt, gm)*
0.0	0.1	0.0	0.0	0.9	0.4	1.1	0.4	0.9	1.1
0.08	0.1	0.0	0.0	0.1	0.1	0.5	0.1	0.3	0.2
0.16	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.1
0.32	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
0.64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Second cropping								
0.0	1.5	1.0	1.5	1.1	1.1	0.9	0.9	1.2	0.8
0.08	1.1	1.2	1.2	0.9	1.3	1.0	1.1	1.2	0.8
0.16	0.9	1.2	1.1	1.0	1.4	1.0	0.9	1.1	1.3
0.32	1.0	0.9	1.2	1.3	1.4	1.5	1.1	1.1	1.1
0.64	0.4	0.5	1.0	1.3	1.5	1.3	0.7	1.2	1.0
1.28	0.7	0.8	1.0	1.1	1.2	0.8	1.1	0.9	0.5
2.56	0.1	0.3	0.6	1.1	1.2	1.1	1.1	0.7	1.3
5.12	0.0	0.0	0.2	0.7	1.1	1.5	0.5	0.4	0.3
10.24	0.0	0.1	0.1	1.0	0.9	1.5	0.1	1.1	0.1
20.48	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0
	Third cropping								
0.0	1.0	1.1	1.0	1.3	1.4	1.7	1.6	1.6	0.9
0.08	0.9	1.2	0.9	1.4	1.6	1.4	1.7	1.7	1.5
0.16	1.2	1.2	1.1	1.3	1.2	1.2	1.3	1.7	1.3
0.32	1.4	1.3	1.4	1.4	1.6	1.5	1.5	1.6	1.1
0.64	1.4	1.3	1.0	1.0	1.4	1.5	1.4	1.4	1.3
1.28	1.9	1.2	1.0	1.3	1.2	1.1	1.5	1.2	1.0
2.56	1.0	1.3	0.9	1.1	1.1	1.4	1.3	1.4	1.3
5.12	1.2	1.3	1.1	1.4	1.4	0.7	1.5	1.5	1.2
10.24	1.1	1.0	0.8	1.4	0.6	1.1	1.4	1.2	1.2
20.48	0.8	1.1	0.7	1.3	1.7	0.5	1.3	0.8	1.1

TABLE 4

Relation Between Toxicity of 2,4-D and Clay Content of Two Yolo Soils

(Values are p.p.m. 2,4-D acid at which growth was severely inhibited)

Soil	Clay	Indicator plant (first crop)	Formulation		
			B.E.	T.E.A.	Na salt
	(per cent)				
Yolo fine sandy loam	14.94	oats	1.60	3.20	3.20
		sunflowers	0.08	0.64	0.64
Yolo adobe clay	50.80	oats	12.80	12.80	12.80
		sunflowers	1.28	1.28	1.28

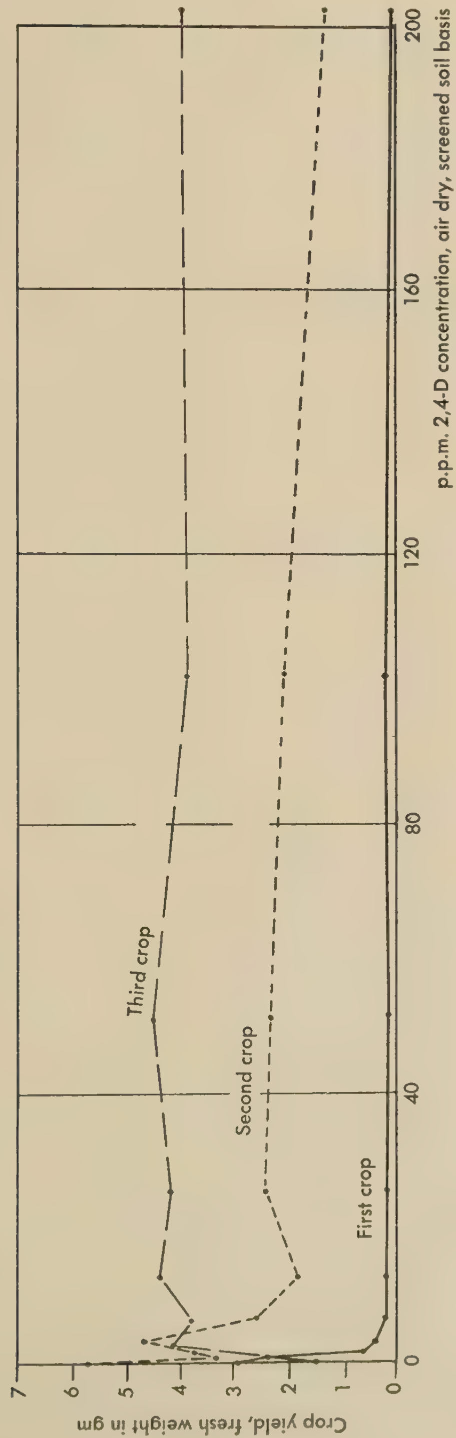

Fig. 1. Toxicity of butyl ester of 2,4-D to oats in Yolo fine sandy loam.

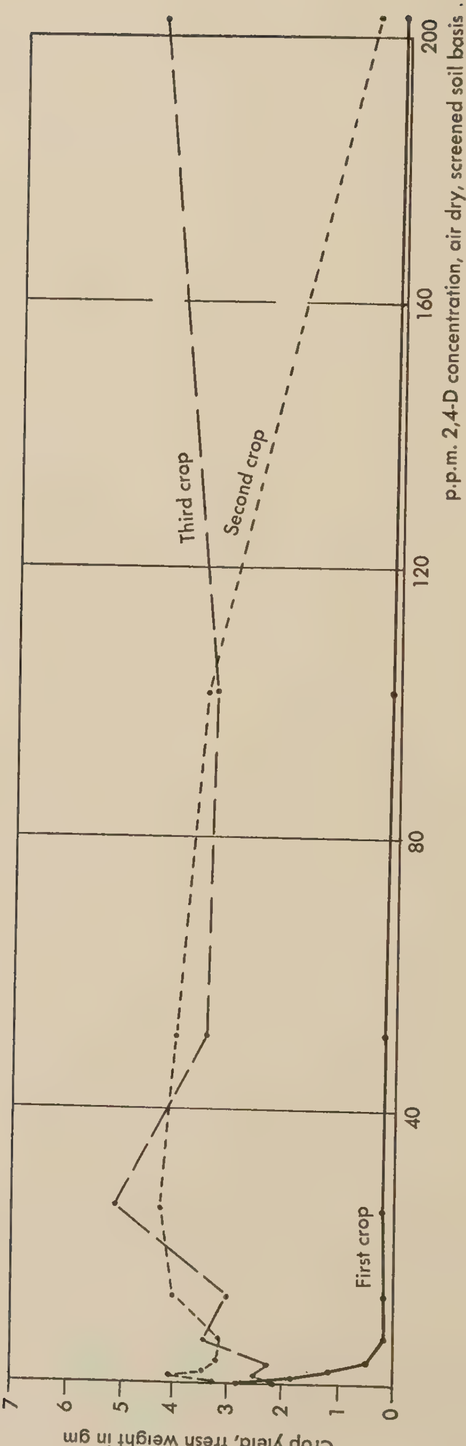

Fig. 2. Toxicity of triethylamine 2,4-D to oats in Yolo fine sandy loam.

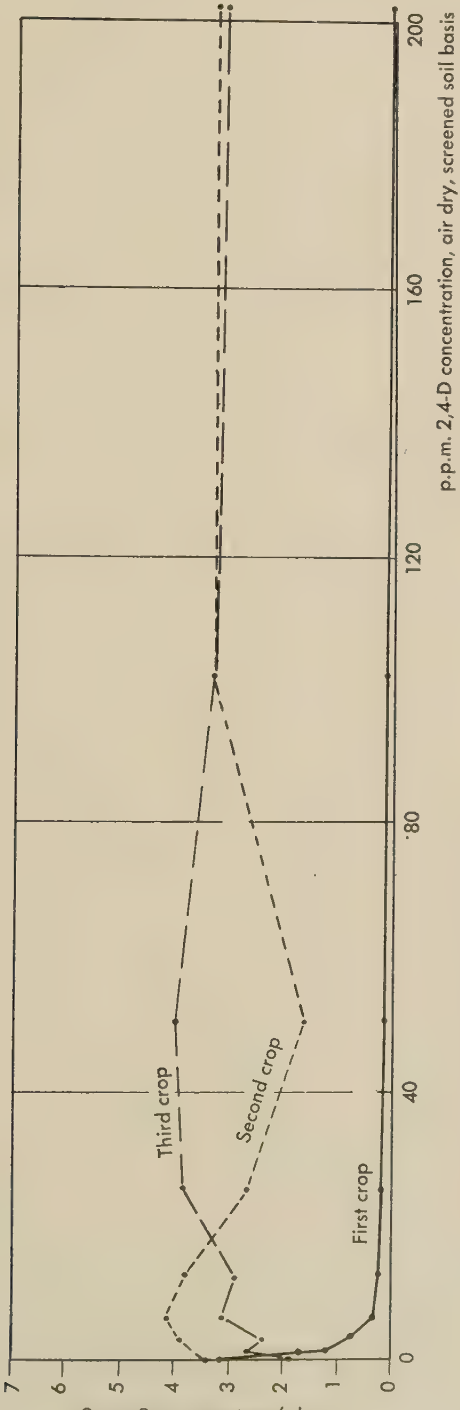

Fig. 3. Toxicity of sodium salt of 2,4-D to oats in Yolo fine sandy loam.

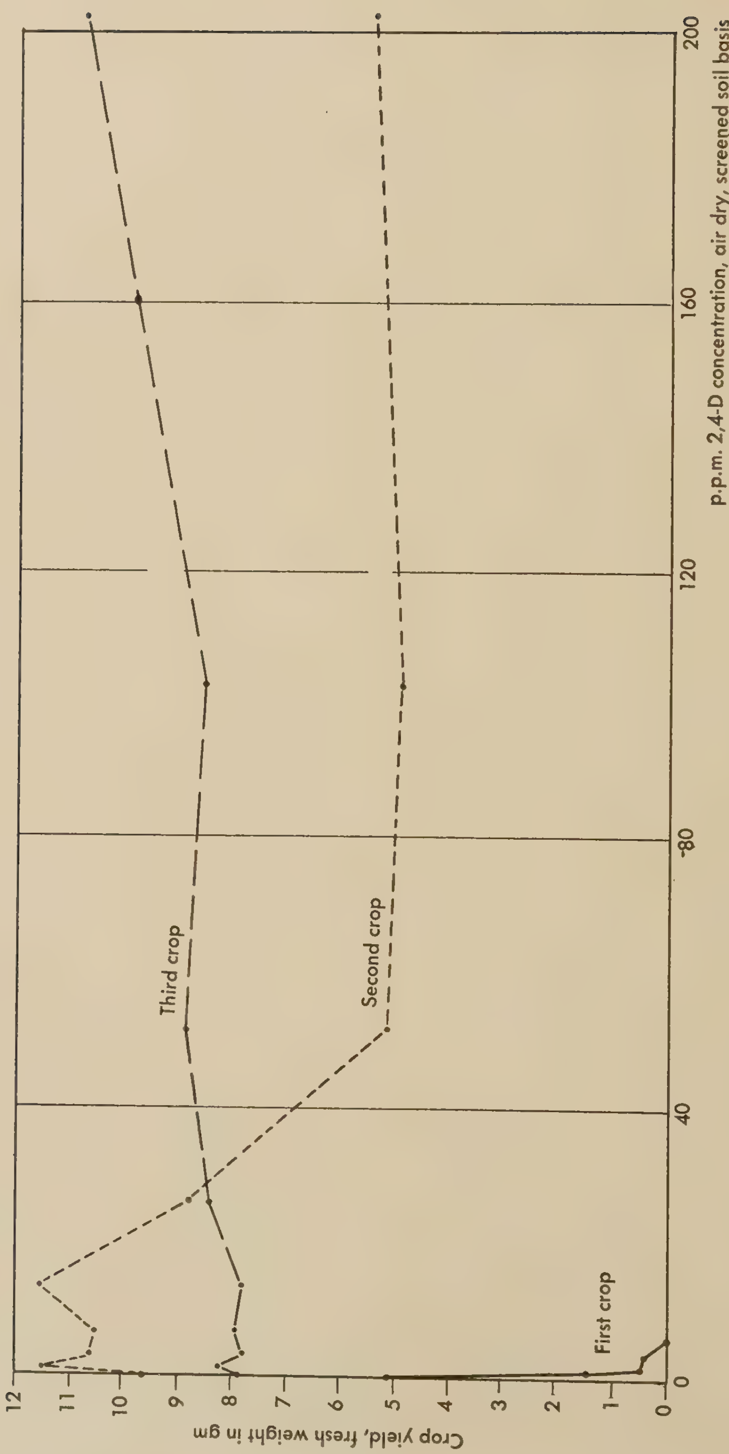

Fig. 4. Toxicity of butyl ester of 2,4-D to sunflowers in Yolo fine sandy loam.

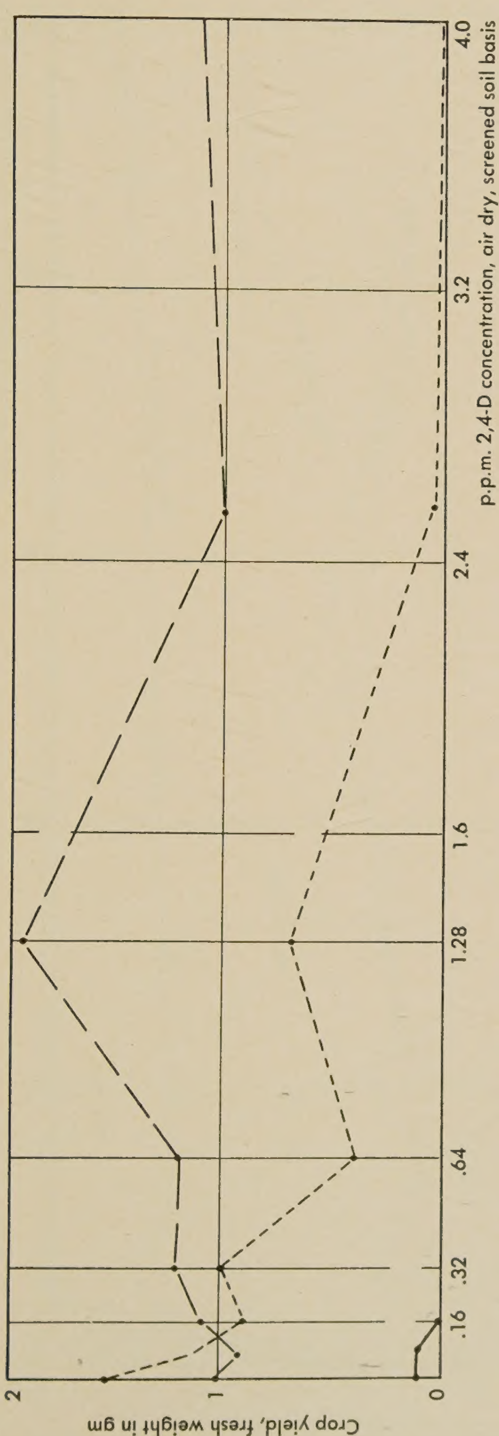

Fig. 5. Toxicity of butyl ester of 2,4-D to vetch in Yolo fine sandy loam.

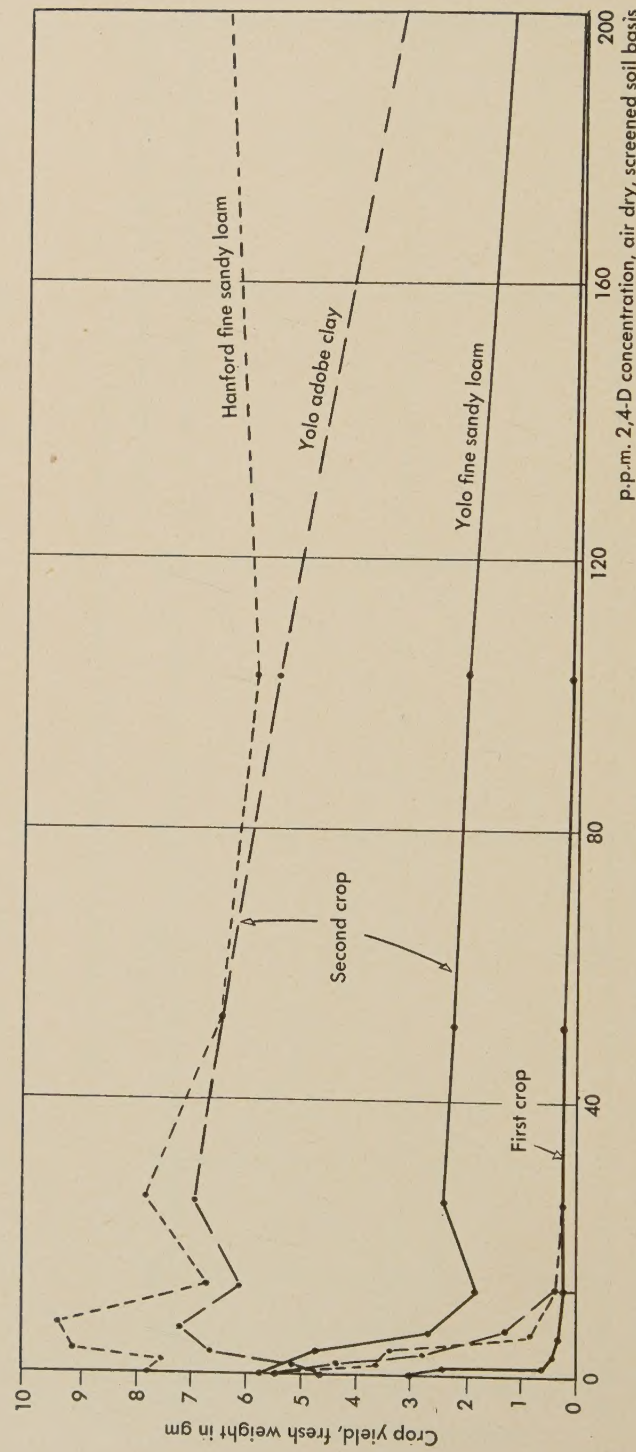

Fig. 6. Toxicity of butyl ester of 2,4-D to oats in three California soils.

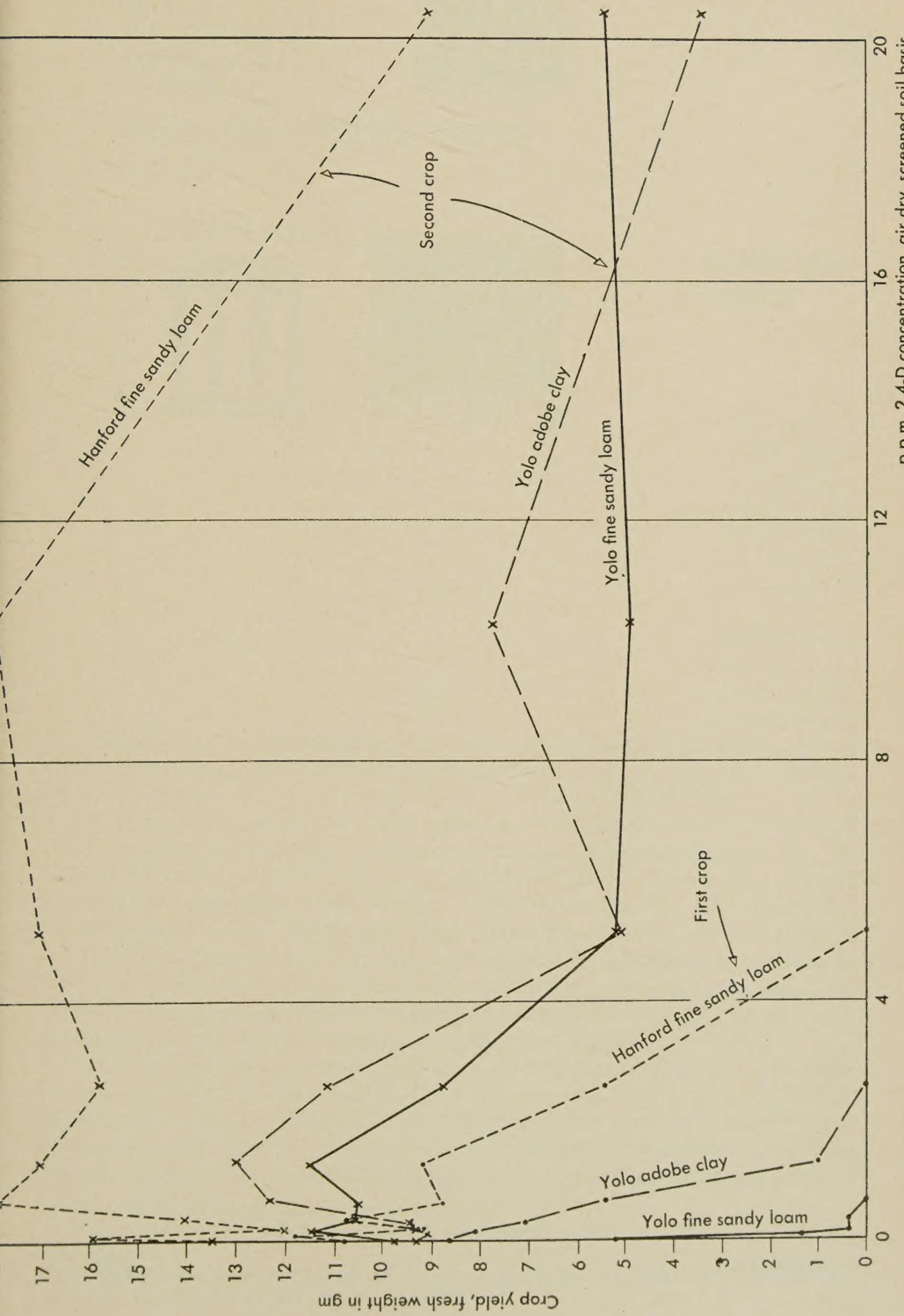

Fig. 7. Toxicity of butyl ester of 2,4-D to sunflowers in three California soils.

4m-8,'52(9950)M.H.